PB95-917001
NTSB/SS-95/01

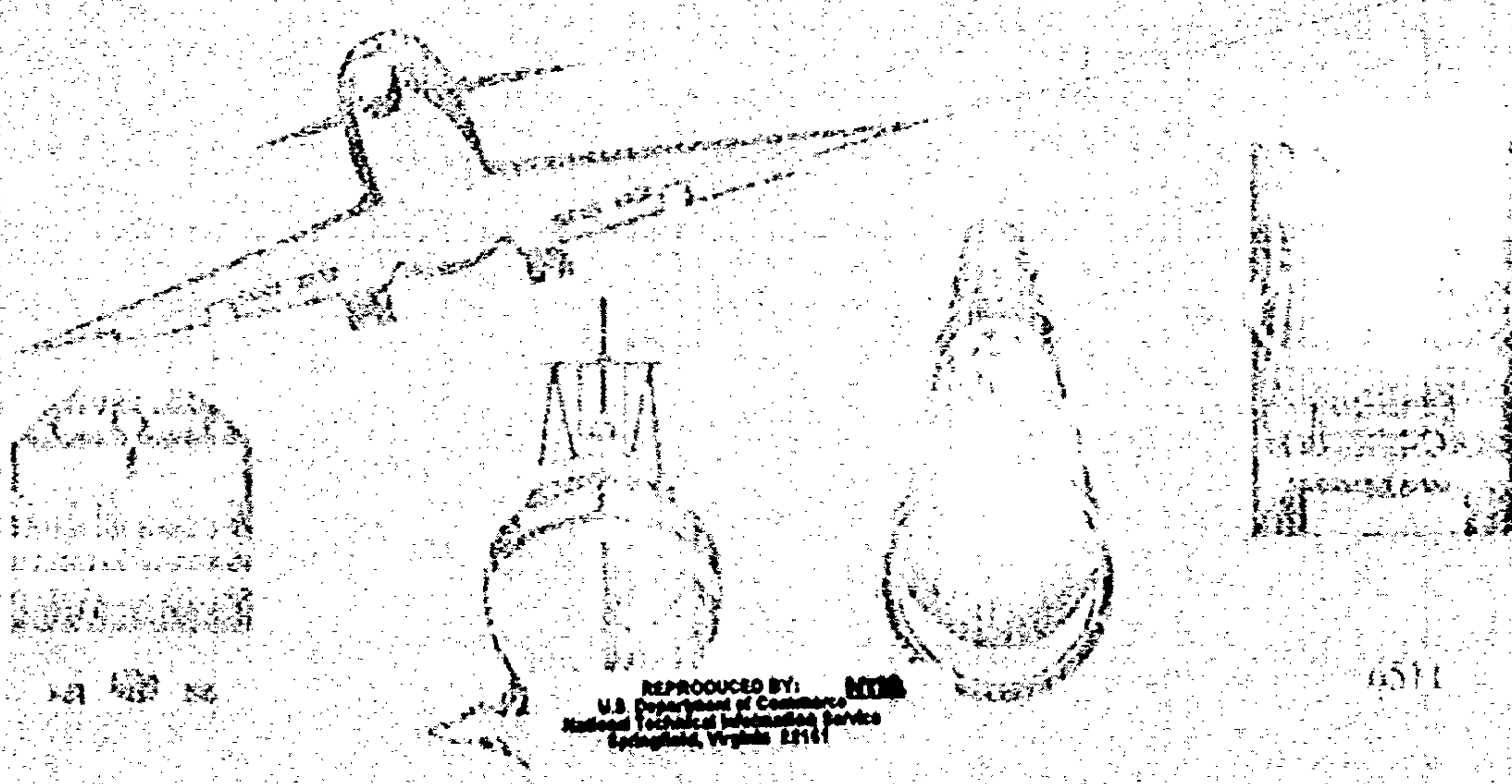
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SAFETY STUDY

FACTORS THAT AFFECT FATIGUE IN HEAVY TRUCK ACCIDENTS

VOLUME 1: ANALYSIS



6511

National Transportation Safety Board. 1995. Factors that affect fatigue in heavy truck accidents. Volume 1: Analysis. Safety Study NTSB/SS-95/01. Washington, DC.

Because of the significant number of heavy truck-related fatalities and the significant role of fatigue in such accidents, the Board initiated this study of single-vehicle heavy truck accidents to examine the role of specific factors, such as drivers' patterns of duty and sleep, in fatigue-related heavy truck accidents and to determine potential remedial actions. The purpose of the Board's study was to examine the factors that affect driver fatigue and not the statistical incidence of fatigue. The study analyzes data from 107 single-vehicle heavy truck accidents in which the driver survived. Volume 1 of the study contains the Board's analysis of the data and its conclusions and recommendations. Volume 2 of the study contains the summaries of the 107 accidents. The safety issues discussed in the report are (a) the factors that affect fatigue-related accidents; (b) the adequacy of the Federal Highway Administration's hours-of-service regulations; and (c) the adequacy of truckdrivers' understanding of the factors affecting fatigue. Safety recommendations concerning these issues were made to the Federal Highway Administration, the Professional Truck Driver Institute of America, the American Trucking Associations, Inc., the Commercial Vehicle Safety Alliance, the National Private Truck Council, the Independent Truck Owner Operators, the Owner-Operator Independent Driver's Association, the International Brotherhood of Teamsters, and the National Industrial Transportation League.

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

Information about available publications may be obtained by contacting:

National Transportation Safety Board
Public Inquiries Section, RE-51
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594
(202)382-6735

Safety Board publications may be purchased, by individual copy or by subscription, from the National Technical Information Service. To purchase this publication, order report number **PB95-917001** from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(703)487-4600

FACTORS THAT AFFECT FATIGUE IN HEAVY TRUCK ACCIDENTS

VOLUME 1: ANALYSIS

Safety Study

Safety Study NTSB/SS-95/01
Notation 6511

National Transportation
Safety Board

Washington, D.C.
January 1995

Contents

Executive Summary

The Safety Board analysis of Fatal Accident Reporting System (FARS) data indicates that in 1993 there were 3,311 heavy trucks involved in 3,169 fatal accidents, in which 3,783 persons died (432 were occupants of the heavy trucks). Research has suggested that truckdriver fatigue may be a contributing factor in as many as 30 to 40 percent of all heavy truck accidents. In 1990, the Safety Board completed a study of 182 heavy truck accidents that were fatal to the truckdriver. These 182 accidents were a census of the heavy truck accidents that were fatal to the driver in the eight participating States. The primary purpose in investigating fatal-to-the-driver heavy truck accidents was to assess the role of alcohol and other drugs in these accidents. The study found, however, that the most frequently cited probable cause was fatigue. The Board believes that the 31-percent incidence of fatigue in fatal-to-the-truckdriver accidents found in the 1990 study represents a valid estimate of the portion of fatal-to-the-driver heavy truck accidents that are fatigue-related.

Because of the significant number of heavy truck-related fatalities and the significant role of fatigue in such accidents, the Board initiated this study of single-vehicle heavy truck accidents to examine the role of specific factors, such as drivers' patterns of duty and sleep, in fatigue-related heavy truck accidents and to determine potential remedial actions. The purpose of the Board's study was to examine the factors that affect driver fatigue and not the statistical incidence of fatigue. Therefore, the Board specifically selected truck accidents that were likely to include fatigue-related accidents; that is, single-vehicle accidents that tend to occur at night. The Board desired to obtain approximately an equal number of fatigue-related and nonfatigue-related accidents through its notification process.

The Board was specifically interested in obtaining accurate information regarding the truckdrivers' duty and sleep patterns for the 96 hours preceding the accident; therefore, the Board limited the accidents to those in which the driver survived and was available to be interviewed by the Board's investigators to reconstruct the previous 96 hours.

The Safety Board investigated 113 single-vehicle heavy truck accidents in which the driver survived. However, because the 96-hour duty/sleep history that was required for the study was not available for 6 drivers, the 6 accidents in which these drivers were involved were not included in the study. The study, therefore, analyzes data from 107 single-vehicle heavy truck accidents.

Based on the determination of probable cause, 58 percent of the accidents (62 of 107) were fatigue-related. The remaining 42 percent of the accidents (45 of 107) were not fatigue-related. Nineteen of the 107 drivers stated that they fell asleep while driving.

The Board emphasizes that the conclusions reached in this study are not based on a set of anecdotal accidents, although the merits of such Board studies have proven valuable in the past. Rather, the results are based on a multivariate statistical analysis (a multiple discriminant analysis) that was performed to simultaneously evaluate the relationship of a set of measures of the drivers' duty and sleep times to the groupings of accidents established by investigators' determination of probable cause (fatigue related and nonfatigue-related accidents). The statistically significant analysis determined that the most important measures in predicting a fatigue-related accident in this sample are the duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep patterns.

Based on the results of the analysis, the safety issues discussed in this study are:

- the factors that affect fatigue-related accidents,
- the adequacy of the Federal Highway Administration's hours-of-service regulations, and
- the adequacy of truckdrivers' understanding of the factors affecting fatigue.

As a result of this study, recommendations were issued to the Federal Highway Administration, the Professional Truck Driver Institute of America, the American Trucking Associations, Inc., the Commercial Vehicle Safety Alliance, the National Private Truck Council, the Independent Truck Owner Operators, the Owner-Operator Independent Driver's Association, the International Brotherhood of Teamsters, and the National Industrial Transportation League. The recommendations focus on the Federal hours-of-service regulations and truckdriver education.

Chapter 1

Introduction

At 1:35 a.m. on May 19, 1993, a tractor with a loaded bulk-cement-tank trailer ran off the road as it was traveling southbound on Interstate 65 (I-65) near Evergreen, Alabama, and struck a bridge support column. The spans of the overpass collapsed onto the semitrailer and the southbound lanes of I-65. The truckdriver probably survived the accident because he was wearing his lap/shoulder belt, which prevented him from being ejected and incurring more severe injuries. Two other southbound vehicles subsequently collided with the fallen bridge spans. Both drivers, the only occupants in these vehicles, sustained fatal injuries. The Safety Board determined that the probable cause of the accident was the truckdriver's failure to maintain his vehicle in the driving lane because of reduced alertness consistent with falling asleep.[1] The truckdriver had reversed his duty and sleep times twice during the 4 days before the accident. Although he had about 10 hours of sleep in his last sleep period, he had been awake for 18 hours and on duty for 8.5 hours at the time of the accident.

A Safety Board analysis of Fatal Accident Reporting System (FARS)[2] data indicates that in 1993 there were 3,311 heavy trucks involved in 3,169 fatal accidents. In these accidents, 3,783 persons died (432 were occupants of the heavy trucks).[3] Truckdriver fatigue was coded as a related factor in 1.67 percent (53 of 3,169) of these fatal heavy truck accidents. The Safety Board believes, however, that driver fatigue is underreported in FARS in general and in FARS specifically with regard to truckdrivers.[4] Research has suggested that truckdriver fatigue may be a contributing

---

[1] National Transportation Safety Board. 1994. Tractor-semitrailer collision with bridge columns on Interstate 65, Evergreen, Alabama, May 19, 1993. Highway Accident Report NTSB/HAR-94/02. Washington, DC.

[2] FARS is maintained by the National Highway Traffic Safety Administration.

[3] For this analysis, the Board defined a heavy truck as one >26,000 pounds gross vehicle weight.

[4] (a) Knipling, Ronald R.; Wang, Jing-Shiarn. 1994. Crashes and fatalities related to driver drowsiness/fatigue. Research Note. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration. November. (b) Pack, Andrew W.; Cucchiara, Andrew; Schwab, C. William, and others. 1994. Characteristics of accidents attributed to the driver having fallen asleep [Abstract]. In: Chase, Michael H.; Krueger, James; O'Connor, Carol, eds. Sleep research. Los Angeles, CA: University of California, Brain Information Service/Brain Research Institute; 23: 141. (c) Pack, Allan I. 1994. Sleep disorders and risk of crashes. In: Åkerstedt, Torbjörn; Keklund, Göran, eds. Work hours, sleepiness and accidents: Proceedings and abstracts; 1994 September 8-10; [Location of meeting unknown]. Stress Research Reports 248. Stockholm, Sweden: National Institute of Psychosocial Factors and Health; Karolinska Institute; WHO Psychosocial Center: 30-32.

factor in as many as 30 to 40 percent of all heavy truck accidents.[5] In 1990, the Safety Board completed a study of 182 heavy truck accidents that were fatal to the truckdriver.[6] These 182 accidents were a census of the heavy truck accidents that were fatal to the driver in the eight States that participated. The primary purpose in investigating fatal-to-the-driver heavy truck accidents was to assess the role of alcohol and other drugs in these accidents. The study found, however, that the most frequently cited probable cause was fatigue. The Board believes that the 31-percent incidence of fatigue in fatal-to-the-truckdriver accidents found in the 1990 study represents a valid estimate of the portion of fatal-to-the driver heavy truck accidents that are fatigue-related. Little data are available to estimate the incidence of fatigue in the less severe heavy truck accidents.

Because of the significant number of heavy truck-related fatalities and the role of fatigue in such accidents, the Board initiated this study of single-vehicle heavy truck accidents to examine the role of specific factors that affect driver fatigue, such as drivers' patterns of duty and sleep, in heavy truck accidents and to determine potential remedial actions. Most research of the factors associated with fatigue involve laboratory studies that examine the effect of sleep deprivation on the operator's performance of specific tasks, such as controlled driving in which various physiological measures are documented, or involve retrospective reviews of accident records, such as police records, which contain limited data and are not designed to assess the role of human performance factors in fatigue-related accidents. The Safety Board is in a unique position to study the role of human performance factors that contribute to fatigue-related accidents. Accident investigation is the primary function of the Board, and it has been examining the role of human performance factors (and fatigue in particular) in accidents in all transportation modes for many years. Therefore, this study of actual accidents provides a unique opportunity to examine the factors that contribute to fatigue-related accidents.

The role of fatigue in transportation has been a concern of the Safety Board for many years. The Safety Board determined that the probable cause of a head-on collision of two freight trains in January 1988, which resulted in fatal injuries to the engineers and brakemen, was the "sleep-deprived condition of the engineer and other crewmembers of [the westbound train], which resulted in their inability to stay awake and alert, and their consequent failure to comply with restrictive signal aspects."[7] The investigation found that none of the crewmembers on the westbound train had more than 2 hours of sleep during the 22 to 24 hours preceding the accident.

---

[5] (a) Knipling and others (1994). (b) Ryder, Andrew, ed. 1990. A system in need of overhaul. In: Driver fatigue, Part 1. Heavy duty trucking. September: 69-73.

[6] National Transportation Safety Board. 1990. Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes. Safety Study NTSB/SS-90/01. Washington, DC.

[7] National Transportation Safety Board. 1989. Head-end collision of Consolidated Rail Corporation freight trains UBT-506 and TV-61 near Thompsontown, Pennsylvania, January 14, 1988. Railroad Accident Report NTSB/RAR-89/02. Washington, DC.

In 1990, the Board determined that the probable cause of the grounding of the *Exxon Valdez* was due, partially, to the failure of the third mate to properly maneuver the vessel because of fatigue and excessive workload.[8] The Board's investigation found that at the time of the grounding, the third mate could have had as little as 5 or 6 hours of sleep in the previous 24 hours, that he had had a physically demanding and stressful day, and that he was working beyond his normal watch period.

Recently, the Board determined that the probable causes of the crash of American International Airways flight 808 at the U.S. Naval Air Station at Guantanamo Bay, Cuba, on August 18, 1993, were the "impaired judgment, decisionmaking, and flying abilities of the captain and flightcrew due to the effects of fatigue...."[9] The investigation of this accident found that the flightcrew members had experienced a disruption of circadian rhythms and sleep loss, which resulted in fatigue that had adversely affected their performance during a critical phase of flight. The flightcrew had been on duty about 18 hours and had flown approximately 9 hours at the time of the accident. Further, although the captain had slept 5 hours in his most recent sleep period, that sleep period started 28.5 hours prior to the accident. Thus, in the 24 hours prior to the accident, the captain had only 0.5 hours of sleep. The first officer had slept 8 hours in his most recent sleep period, 5 hours of which were in the 24 hours before the accident. The flight engineer had slept 6 hours in his last sleep period, 4 hours of which were in the 24 hours before the accident.

Historically, fatigue was typically viewed as a simple condition directly related to the amount of time spent working at a given task, such as driving.[10] The hours-of-service regulations in the motor carrier industry were written from this viewpoint,[11] and a 1940 government study of truckdriver fatigue was conducted from this perspective as well.[12] Modern scientific research has shown that fatigue, and specifically driver fatigue, is related to much more than just the amount of time spent

---

[8] National Transportation Safety Board. 1990. Grounding of the U.S. tankship *Exxon Valdez* on Bligh Reef, Prince William Sound near Valdez, Alaska, March 24, 1989. Marine Accident Report NTSB/MAR-90/04. Washington, DC. (Costs associated with this accident are estimated in the billions of dollars.)

[9] National Transportation Safety Board. 1994. Uncontrolled collision with terrain [of] American International Airways flight 808, Douglas DC-8-61, N814CK, at the U.S. Naval Air Station in Guantanamo Bay, Cuba, August 18, 1993. Aircraft Accident Report NTSB/AAR-94/04. Washington, DC.

[10] McDonald, Nicholas. 1984. Fatigue, safety and the truck driver. London; Philadelphia: Taylor & Francis (p. 104-115). 218 p.

[11] 3 M.C.C. 667, December 29, 1936; 28 M.C.C. 125; 11 M.C.C. 206, January 27, 1939; March 4, 1941.

[12] U.S. Public Health Service, Federal Security Agency. 1941. Fatigue and hours of service of interstate truck drivers. Public Health Bulletin No. 265. Washington, DC.

working.[13,14] Researchers have examined the relationship of fatigue to physical work and overexertion,[15,16] shiftwork,[17] circadian rhythms,[18] and the duration and quality of sleep.[19,20] (See appendix A for a discussion of basic human physiology regarding sleep and circadian rhythms.)

Sleep is a vital physiological requirement: people need sleep just as they need food and water.[21] Although individual differences exist, research has shown that everyone needs a specific amount of sleep in each 24-hour period, and that without this amount of sleep, subsequent alertness will be compromised.[22] Cumulative sleep loss and circadian disruption can lead to a physiological state characterized by

---

[13] Brown, Ivan D. 1994. Driver fatigue. Human Factors. 36(2): 298-314.

[14] Paley, M.J.; Tepas, D. 1994. Fatigue and the shiftworker: firefighters working on a rotating shift schedule. Human Factors. 36(2): 269-284.

[15] Mital, A.; Foononi-Fard, H.; Brown, M. 1994. Physical fatigue in high and very high frequency manual materials handling: perceived exertion and physiological indicators. Human Factors. 36(2): 219-231.

[16] Kumar, S. 1994. A conceptual model of overexertion, safety, and risk of injury in occupational settings. Human Factors. 36(2): 197-209.

[17] Folkard, S.; Monk, T.H.; Lobban, M.C. 1979. Towards a predictive test of adjustment to shiftwork. Ergonomics. 21: 785-799.

[18] Mackie, R.R., ed. 1977. Vigilance: theory, operational performance, and physiological correlates. New York: Plenum.

[19] Johnson, L.C.; Naitoh, P. 1974. The operational consequences of sleep deprivation and sleep deficit AGARD-AG-193, NATO. London: Technical Editing and Reproduction.

[20] Rosekind, M.R.; Gander, P.H.; Connell, L.J.; Co, E.L. 1994. Crew factors in flight operations X: alertness management in flight operations. NASA/FAA Technical Memorandum DOT/FAA/RD-93/18.

[21] Carskadon, M.; Dement, W 1982. Nocturnal determinants of daytime sleepiness. In: Sleep. 8: 11-19.

[22] (a) Carskadon, Mary A.; Dement, William C. 1994. Normal human sleep: an overview. In: Kryger, M.; Roth, T.; Dement, W.C., eds. Principles and practice of sleep medicine. 2d ed. Philadelphia: W.B. Sanders Company: 16-26. Section 1, chapter 2. (b) Roth, Thomas; Roehrs, Timothy A.; Carskadon, Mary A.; Dement, William C. 1994. Daytime sleepiness and alertness. In: Kryger, M.; Roth, T.; Dement, W.C., eds. Principles and practice of sleep medicine. 2d ed. Philadelphia: W.B. Sanders Company: 40-50. Section 1, chapter 4. (c) National Commission on Sleep Disorders Research. 1993. Wake up America: a national sleep alert. Vol. 1: Executive summary and executive report. Report submitted to the U.S. Congress and to the Secretary, U.S. Department of Health and Human Services. Washington, DC: U.S. Department of Health and Human Services. 76 p.

impaired performance and diminished alertness.[23] The word "fatigue" is commonly used to describe this kind of impairment.

Fatigue is associated with sleep loss and influenced by the body's own internal clock. It is clear that fatigued people need to sleep, and laboratory research has demonstrated that they have measurable performance decrements as well as an increased tendency to lapse into sleep involuntarily.[24] People often do not realize that they are fatigued, or they overestimate their alertness.[25] Drivers frequently attribute feelings of sleepiness to boredom or a recent meal.[26] Fatigue can impair information processing and reaction time, increasing the probability of errors and ultimately leading to accidents.[27]

The Safety Board recognizes that the effects of fatigue range from relatively subtle impairment to overt incapacitation. The Board examined the effect of fatigue on operator judgment and behavior in its investigations of the grounding of the tankship *Exxon Valdez* and the airplane crash at Guantanamo Bay, Cuba. These accidents both involved a multi-person crew environment in which actions and judgments were verbalized. This led to a rich source of information for investigators through witness statements and recorded data. In most trucking accidents, it is generally difficult to obtain the type of information that is often readily available during the investigation of accidents in other modes, such as information from the cockpit voice recorder or air traffic control services in the aviation mode as an example. In the Safety Board's sample cases for this study, a determination of driver fatigue was based on evidence that the driver fell asleep, either by the driver's self-report that he fell asleep or the physical evidence at the scene of the accident.

---

[23] (a) Rosekind, Mark R.; Graeber, R. Curtis; Dinges, David F.; and others. 1993. Crew factors in flight operations. IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations. NASA Technical Memorandum 108839. DOT/FAA/92/24. Washington, DC. (b) Torsvall, L.; Akerstedt, T. 1987. Sleepiness on the job: continuously measured EEG changes in train drivers. Electroencephalography and Clinical Neurophysiology. 66: 502-511.

[24] (a) Rosekind and others (1993). (b) Torsvall and Akerstedt (1987).

[25] (a) National Commission on Sleep Disorders Research (1993). (b) Sasaki, M.; Kurosaki, Y.; Mori, A.; Endo, S. 1986. Patterns of sleep-wakefulness before and after transmeridian flight in commercial airline pilots. Aviation, Space, and Environmental Medicine. 57(12): B29-B42. (c) Neville, Kelly J.; Bisson, Roger U.; French, Jonathan; and others. 1994. Subjective fatigue of C-141 aircrews during operation Desert Storm. Human Factors. 36(2): 339-349.

[26] (a) Dinges, D.F. 1989. The nature of sleepiness: causes, context, and consequences. In: Stunkard, A.; Baum, A., eds. Perspectives in behavioral medicine: eating, sleeping, and sex. Hillsdale, NJ: Lawrence Erlbaum: 147-179. Chapter 9. (b) Dinges, D.F. 1992 Probing the limits of functional capability: the effects of sleep loss on short-duration tasks. In: Broughton, R.J.; Ogilvie, R., eds. Sleep, arousal, and performance. Boston: Birkhauser-Boston, Inc.: 176-188. Chapter 12.

[27] Dinges (1989; 1992).

Chapter 2 describes in more detail the methodology of the study, including accident selection criteria, notification procedures, investigative data collected, determination of probable cause, and various duty/sleep time measures examined in the study. Chapter 3 provides an overview of the accidents, including a brief discussion of the characteristics of the drivers, the trips, the vehicles, and the motor carriers. Chapter 4 analyzes drivers' patterns of duty and sleep. Chapter 5 provides a summary of the results of the analysis of the drivers' duty/sleep time measures. The last sections present the Safety Board's conclusions and recommendations made as a result of this study.

Chapter 2

Methodology

Selection and Notification Criteria

The Safety Board selected for the study single-vehicle accidents in which a heavy truck (>26,000 pounds gross vehicle weight) was involved and the driver survived.[28] Because the purpose of the Board's study was to examine the factors that affect driver fatigue and not the statistical incidence of fatigue, the Board specifically selected truck accidents that were likely to include fatigue-related accidents; that is, single-vehicle accidents that tend to occur at night. The Board desired to obtain approximately an equal number of fatigue-related and nonfatigue-related accidents through its notification process to examine the differences between the two groups. From September 1992 through June 1993, the Board was notified by authorities in the States of Alabama, California, Georgia, New Jersey, North Carolina, and Texas[29] of single-vehicle accidents. During this period, the Board accepted sequentially for investigation, with no prejudgment of fatigue involvement, those accidents that occurred within a reasonable driving distance from the Board's regional offices and in which the vehicle was available for examination and the driver was available to be interviewed.

The Board was specifically interested in obtaining accurate information regarding the truckdrivers' duty and sleep patterns for the 96 hours preceding the accident; therefore, the Board limited the accidents to those in which the driver survived and was available to be interviewed by the Board's investigators to reconstruct the previous 96 hours. The Federal Highway Administration's (FHWA) hours-of-service (HOS) regulations are addressed in Section 395 of Title 49 of the Code of Federal Regulations (49 CFR Section 395); Section 395.8 addresses requirements for drivers to maintain official log books of duty and driving time. However, the Board did not rely solely on the drivers' official log books because of concern that inaccurate or incomplete information might have been recorded and because total sleep time is not required to be reported. (Pertinent sections of the FHWA's HOS regulations are discussed later in this study.)

---

[28] Single-vehicle refers to both a single unit or combination unit vehicle.

[29] According to FARS data, in 1992 about 27 percent of fatal accidents involving large trucks in the United States occurred in these six States.

The Safety Board acknowledges that the accuracy of the self-reported 96-hour duty/sleep history data is dependent on the ability (given memory limitations) and the willingness of the drivers to provide accurate information. In most cases, the drivers were interviewed within hours of the accident. Although the drivers were not given any promise of anonymity, the drivers' legal exposure was limited because of the lack of severity of the majority of the single-vehicle accidents.

The Safety Board investigated 113 single-vehicle heavy truck accidents in which the driver survived. However, because the 96-hour duty/sleep history that was required for the study was not available for 6 drivers, the 6 accidents in which these drivers were involved were not included in the study. The study, therefore, analyzes data from 107 single-vehicle heavy truck accidents.[30]

Investigative Procedures

The Board used its standard investigative and probable cause determination procedures for the 107 cases. Although the accident scene was not normally secured for the Board's investigators, an onsite investigation was conducted for each accident to document the physical evidence at the scene. Because of its expertise in conducting thorough accident investigations for more than 27 years, the Board's investigators can readily recognize and obtain the important physical evidence that remains after an accident. In virtually all highway accidents, there is adequate physical information remaining on scene to reconstruct the accident sequence. In addition, Board investigators obtained pertinent information from the motor carriers (including copies of the drivers' 30-day log entries[31] prior to the accident) and from the police agencies that responded to the accidents.

In addition to reconstructing the 96 hours preceding the accident during an interview with Safety Board investigators, each driver was asked to respond to a standard set of questions. The questionnaires were based on the Board's accident investigation expertise and experience with fatigue-related and heavy truck accidents, the fatigue research literature, and in consultation with national experts.[32] The

---

[30] Volume 2 of this study contains the briefs of the 107 accidents investigated by the Safety Board.

[31] According to 49 CFR 395.8(k)(1), driver logs for each calendar month are required to be retained at the driver's home terminal until the 20th day of the succeeding month. The logs are then forwarded to the carrier's principal place of business to be retained with all supporting materials for 6 months from the date of receipt. According to 49 CFR 395.8(k)(2), drivers must have logs for the previous 7 consecutive days in their possession while on duty.

[32] Dr. Mark Rosekind (NASA Ames Research Center), Dr. David Dinges (Unit for Experimental Psychology, University of Pennsylvania), Dr. Robert Makie (private consultant), and Dr. William (continued...)

questionnaires requested information from the drivers on such topics as duty/sleep history, work activity, educational background, and medical history. In addition, several questions were directed to the carriers regarding motor carrier operations[33] and driver oversight. Followup contacts were made to verify the drivers' responses to the questionnaire, when deemed necessary.

Postaccident drug testing is not usually performed in the types of accidents in the Board's sample. The FHWA postaccident drug testing policy includes any reportable accident (greater than $4,400 property damage, or resulting in any injury or death) in which a driver is issued a citation for a moving violation and for all fatal accidents even if the driver is not cited; however, it is unlikely that many drivers in the sample met the criteria for testing.[34] The Board did not specifically collect information on the property damage costs of the accidents or whether the driver was cited for the accident, and this information was not uniformly documented on the police reports.

Following the investigators' submission of detailed reports of the accidents, a panel of Safety Board staff then reviewed each case to assure that accident information and vehicle and physical evidence were used appropriately and consistently to determine the probable cause.[35] The evidence upon which a probable cause determination of fatigue involvement was based fell into one of three categories. For the first category, the driver explicitly stated that he fell asleep or dozed off. For the second category, the key factor for a probable cause determination of fatigue involvement was a preponderance of physical evidence consistent with a driver whose level of alertness was diminished or who fell asleep, such as a shallow departure angle from the roadway, no corrective steering or braking inputs, or other inappropriate driving maneuvers. In this second category, some corroborating information from the driver's 96-hour duty/sleep history consistent with the physical evidence may have existed; however, the critical factor for a determination of fatigue involvement in this category was the physical evidence. In the third category, evidence for a probable cause determination of fatigue involvement was either information in the driver's 96-hour duty/sleep history that suggested a reduced state

---

[32] (...continued)
Dement (Sleep Disorders Center, Stanford University). These experts provided information on duty/sleep cycles, sleep disorders, circadian rhythms, nutrition, physical fitness, and drug interaction with sleepiness.

[33] Trucking industry representatives provided information to the Board on motor carrier policies and practices regarding loading/unloading requirements, scheduling, pay methods, and log book requirements.

[34] Alcohol testing rules did not go into effect until January 1, 1995. The rules apply to postaccident testing of commercial motor vehicle drivers.

[35] The review panel comprised five Safety Board staff members: two from the Office of Research and Engineering, Safety Studies Division; and three from the Office of Surface Transportation Safety, Highway Accident Division and Human Performance Division.

of alertness or sleep loss, or some physical evidence. In the fatigue-related accidents, fatigue was cited as either a primary cause or contributing cause.

The nonfatigue-related accidents included those in which the probable cause was determined to be speeding or driving too fast for conditions, mechanical defects with the vehicle, load shifts, poor weather conditions, or roadway hazards. In none of these cases did the drivers indicate that they had fallen asleep nor was there any physical evidence consistent with falling asleep. Coincidentally, there was no obvious evidence in the driver's 96-hour duty/sleep history that would suggest a reduced state of alertness or sleep loss.

Duty/Sleep Time Measures

The Board examined several measures of duty time, driving time, awake time, and sleeping time for the drivers. These measures included (1) the number of hours awake, driving, on duty, and sleeping in the 24-, 48-, 72-, and 96-hour periods before the accident, (2) the number of hours driving since the driver had last slept, (3) the number of hours driving in the period most recent to the accident, (4) the number of hours on duty prior to the accident (including nondriving activities such as loading and unloading cargo, truck inspections, paperwork, calling dispatchers, and waiting at terminals), (5) the number of hours since the driver had last slept, and (6) the number of hours slept in the sleep period most recent to the accident.[36, 37] These measures were taken from the 96-hour logs that were reconstructed from the Safety Board investigators' interviews with the drivers.

Regularity/Irregularity of Drivers' Duty/Sleep Patterns

The Board also examined the drivers' duty/sleep patterns for the 96-hour period before the accident. The Board established five classifications of the drivers'

---

[36] The difference between the number of hours since the driver had last slept and the number of hours slept in the past 24 hours would be affected by naps of less than 1 hour or if the accident occurred more than 24 hours after the time the driver went to sleep. For example, a driver went to sleep at 10 p.m. on Sunday and slept 8 hours until 6 a.m. Monday. If the accident occurred at 11 p.m. on Monday, the driver would have had 7 hours of sleep in the 24-hour period before the accident and 8 hours in the period most recent to the accident.

[37] For purposes of discussion in this study, these measures have been termed "duty/sleep time measures."

duty/sleep patterns. For the purposes of this study, a "duty period" was defined as a work period (driving or on duty not driving) that was not interrupted by more than 1 hour of off-duty time. If a break or off-duty time of more than 1 hour occurred, the duty period that followed the break was considered to be a new duty period.[38] A driver's duty hours were classified (as regular or irregular) only if at least three consecutive duty start times (no days off between start times) occurred in the 96-hour period before the accident. If a driver did not have at least three consecutive start times, his duty hours were considered "nonclassifiable."

A "sleep period" was defined as such only if it lasted more than 1 hour. (It should be noted that cumulative sleep has been accounted for in the measures discussed previously, and that the sleep period of an hour or more is being defined here for the sole purpose of determining patterns of sleep.) A driver's sleep hours were classified (as regular or irregular) only if at least three consecutive sleep start times occurred in the 96-hour period before the accident. All drivers exhibited sleep periods that could be classified. The five dichotomous (yes/no) measures included irregular duty, irregular sleep, both irregular duty and sleep, regular duty and sleep, and regular sleep with nonclassifiable duty. The rules applied to determine these measures are detailed in table 2.1. These five measures are mutually exclusive. The Board also identified three other schedule-related measures that could occur for a driver with either regular or irregular duty/sleep patterns. They include inverted duty/sleep, split sleep patterns, and exceeded hours-of-service limits (exceeded HOS limits). The rules applied to determine these measures are also discussed in table 2.1. The Safety Board acknowledges that the definitions of sleep and duty are arbitrary and that there may be other ways to define these terms. The Board's analysis in chapter 4 addresses the import of the definitions of duty and sleep used in this study.

---

[38] Consideration of a longer off-duty period (2 hours) is addressed in chapter 4.

Table 2.1—Measures of drivers' schedules and rules applied to determine the measures

Measure	Rule
Duty/sleep pattern:	
Irregular duty hours	A driver's duty hours were classified as irregular if the start times of two consecutive duty periods varied by 2 or more hours at least twice during the period considered (96-hour period). In cases where the 96-hour break-off occurred within a duty or sleep period, the start time of that duty or sleep period was the starting point of the data.
Irregular sleep hours	A driver's sleep hours were classified as irregular if the start times of two consecutive rest periods varied by 2 or more hours at least twice during the period considered (96-hour period). In cases where the 96-hour break-off occurred within a duty or sleep period, the start time of that duty or sleep period was the starting point of the data.
Irregular duty/sleep hours	A driver's duty/sleep hours were classified as irregular if the start times of two consecutive duty periods and the start times of two consecutive sleep periods both varied by 2 or more hours at least twice during the period considered (96-hour period).
Regular duty/sleep hours	A driver's duty/sleep hours were classified as regular if none of the above three categories were applicable.
Regular sleep with nonclassifiable duty hours	A driver's duty/sleep hours were placed in this category if the sleep hours were regular, but there were not enough consecutive duty shifts to classify duty hours.
Other schedule-related measures:	
Inverted duty/sleep	The times slept and on duty were reversed from one 24-hour period to the next. That is, the driver's accident occurred at a time when on the previous day the driver had been sleeping.
Split sleep pattern	If the duration of each of the driver's multiple sleep periods in the 96-hour history was consistently less than 6 hours.
Exceeded hours-of-service limits	If the driver exceeded the 10-hour driving rule or the 15-hour on-duty rule at any time during the 96-hour history.

Chapter 3

Overview of the Accidents

The information in this chapter provides an overview of the 107 accident cases to acquaint the reader with general characteristics of the accidents, the drivers, the vehicles, and the motor carriers. The Board emphasizes that the characteristics described in this section are of a selected sample of accidents and that the information cannot be extrapolated to the general population or used to estimate the statistical incidence of fatigue in heavy truck accidents.

Fatigue Involvement

Based on the determination of probable cause, 58 percent of the accidents (62 of 107) were fatigue-related. Nineteen drivers in the fatigue-related accidents stated that they fell asleep while driving. The remaining 42 percent of the accidents (45 of 107) were not fatigue-related.

Type of Accident

The vehicle ran off the road and then overturned in 44 of the 107 accidents analyzed in this study; fatigue was involved in 75 percent of these accidents (33 of 44). The vehicle overturned on the roadway in 24 of the accidents. The vehicle simply ran off the road and remained upright in 17 accidents, and the vehicle jackknifed in 7 of the accidents. In the remaining 15 accidents, some other combination of the above occurred (see figure 3.1).

Time of Day

Seventy of the 107 accidents occurred between 10 p.m. and 8 a.m. (see figure 3.2); about 74 percent of these accidents (52 of 70) were fatigue-related. Of the accidents that occurred between 8 a.m. and 10 p.m., 73 percent were not fatigue-related (27 of 37).

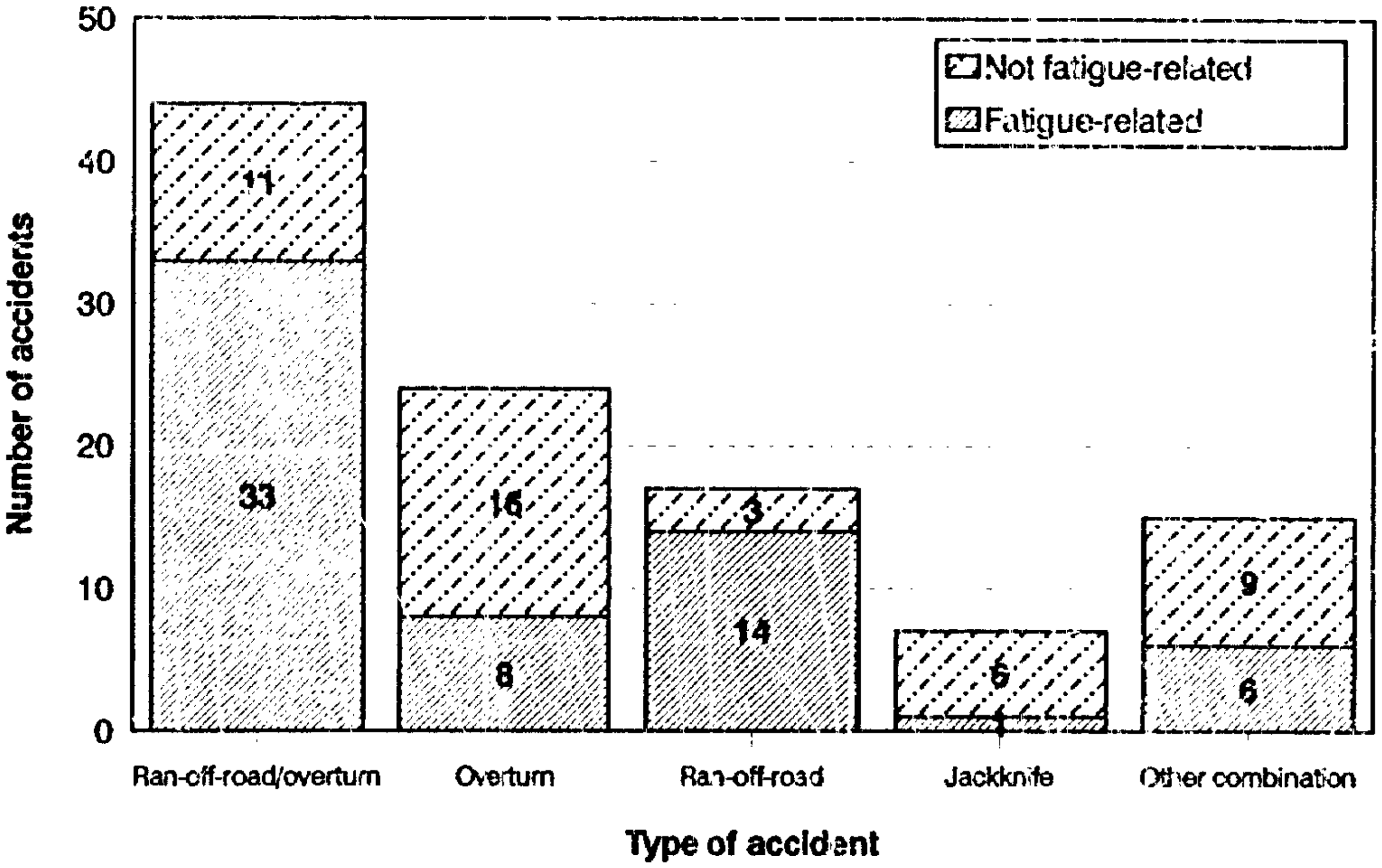


Figure 3.1—Number of accidents by type of accident and fatigue involvement.

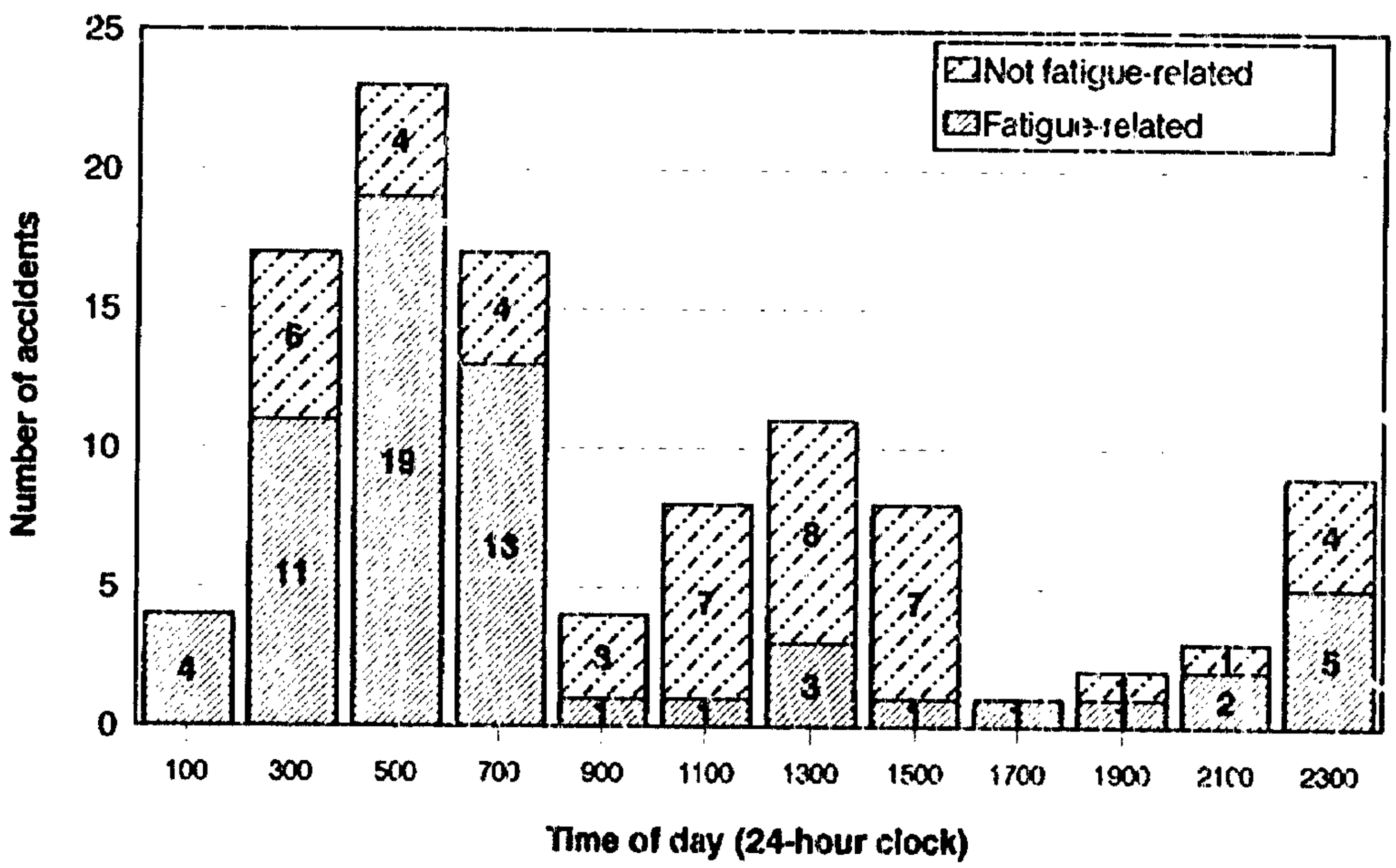


Figure 3.2—Number of accidents by time of day and fatigue involvement.

Traffic and Roadway Information

As was expected with a sample of single-vehicle accidents, many of the accidents (83) occurred during light or sparse traffic conditions.[39] The number of fatigue- and nonfatigue-related accidents under these traffic conditions was about equal.

Of the 107 accidents, 69 occurred on dry roadways, 59 occurred on limited access roadways, and 63 occurred on divided highways.

Driver Information

Age, Experience, and Training.—The mean age of the drivers in this sample was 38 with a range from 20 to 67 years. The mean number of years of experience was 13, ranging from less than 1 year to 37 years. (See figures 3.3 and 3.4.)

All but one of the drivers held a commercial driver license (CDL) (one driver was scheduled to take the CDL test and had a valid Texas class C operator license at the time of the accident). In addition, 85 drivers reported receiving either on-the-job training (55), training from the carrier (30), or training by attending a formal truckdriving course (27).[40] There was no apparent relationship between fatigue and age, experience, or training within the accident sample.

Health.—All drivers reported their health, vision, and hearing to be good. Nineteen drivers reported taking some kind of over-the-counter medication on a regular basis; 38 drivers reported taking medicine on the accident trip. The most widely taken over-the-counter drug was a pain reliever (aspirin), 15 of the 19 drivers responding to this question reported using this type of drug. The drivers reported that their energy level on the accident trip was normal. The drivers' reports of physical discomfort, environmental stress, worriedness, and anxiousness on the accident trip were not significantly different for the drivers in fatigue-related and nonfatigue-related accidents.

---

[39] Light or sparse traffic conditions is a category on the Safety Board's standard investigation form.

[40] The numbers do not add to 85 because some drivers received more than one type of training.

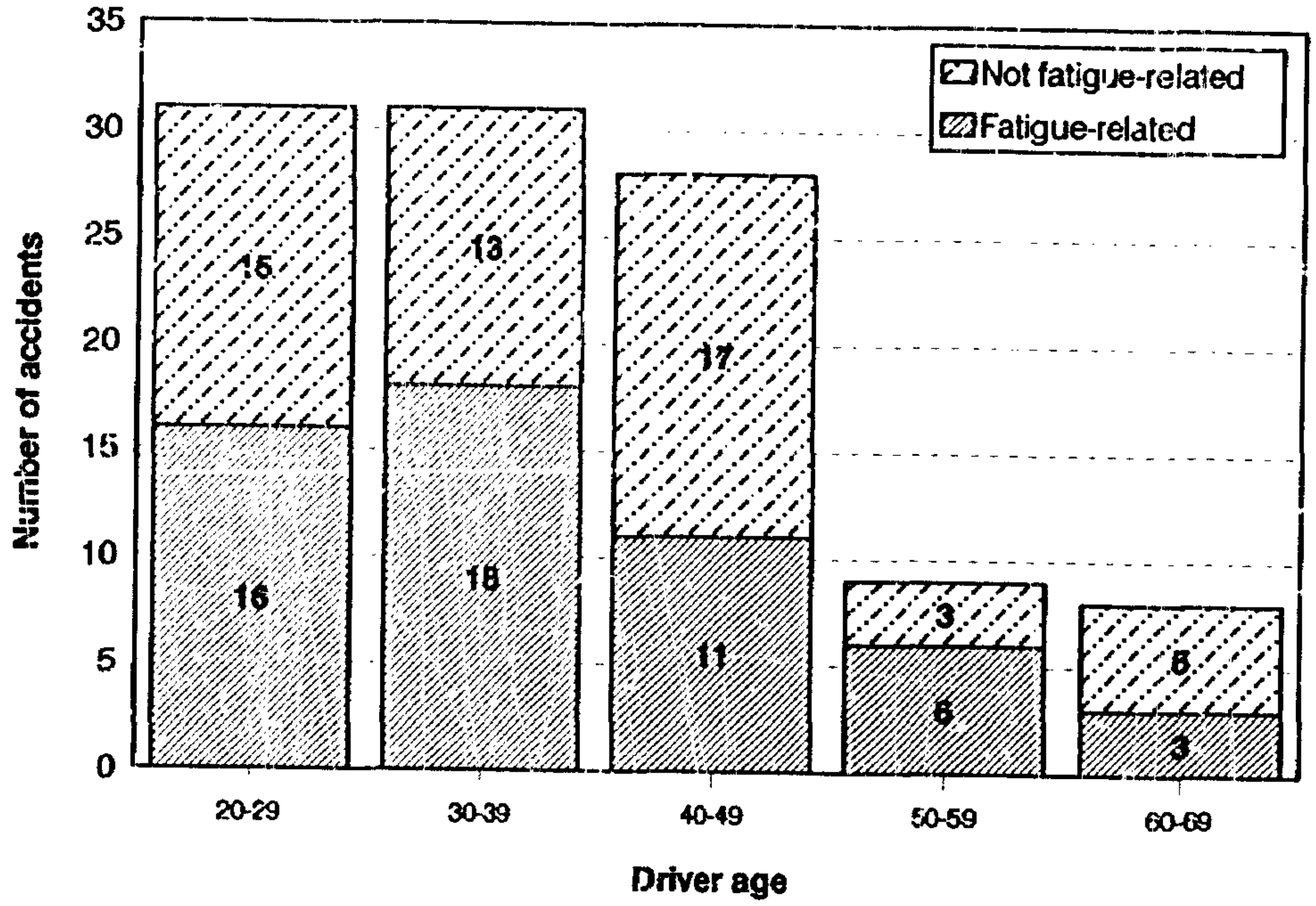


Figure 3.3—Number of accidents by driver age and fatigue involvement.

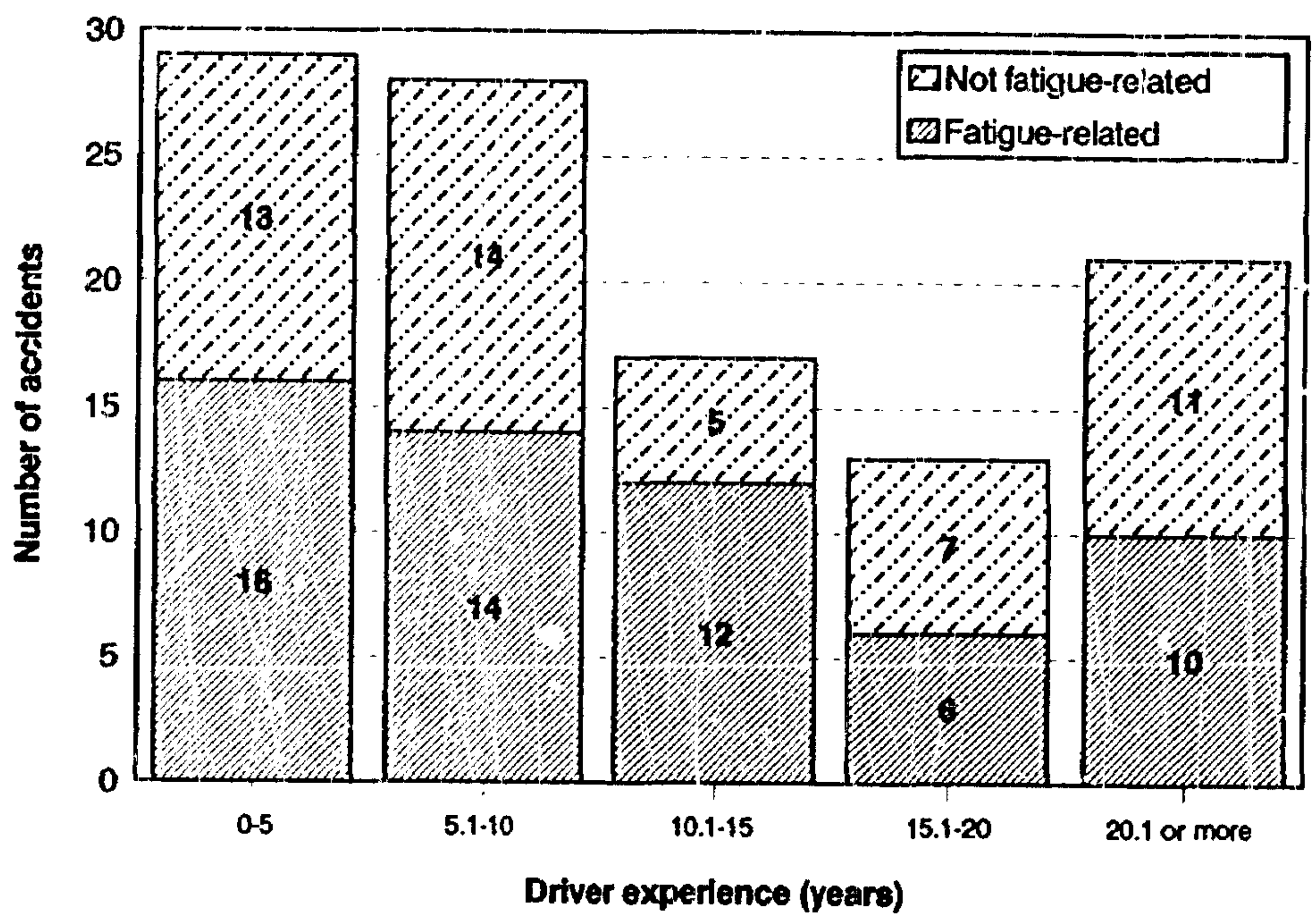


Figure 3.4—Number of accidents by driver experience and fatigue involvement.

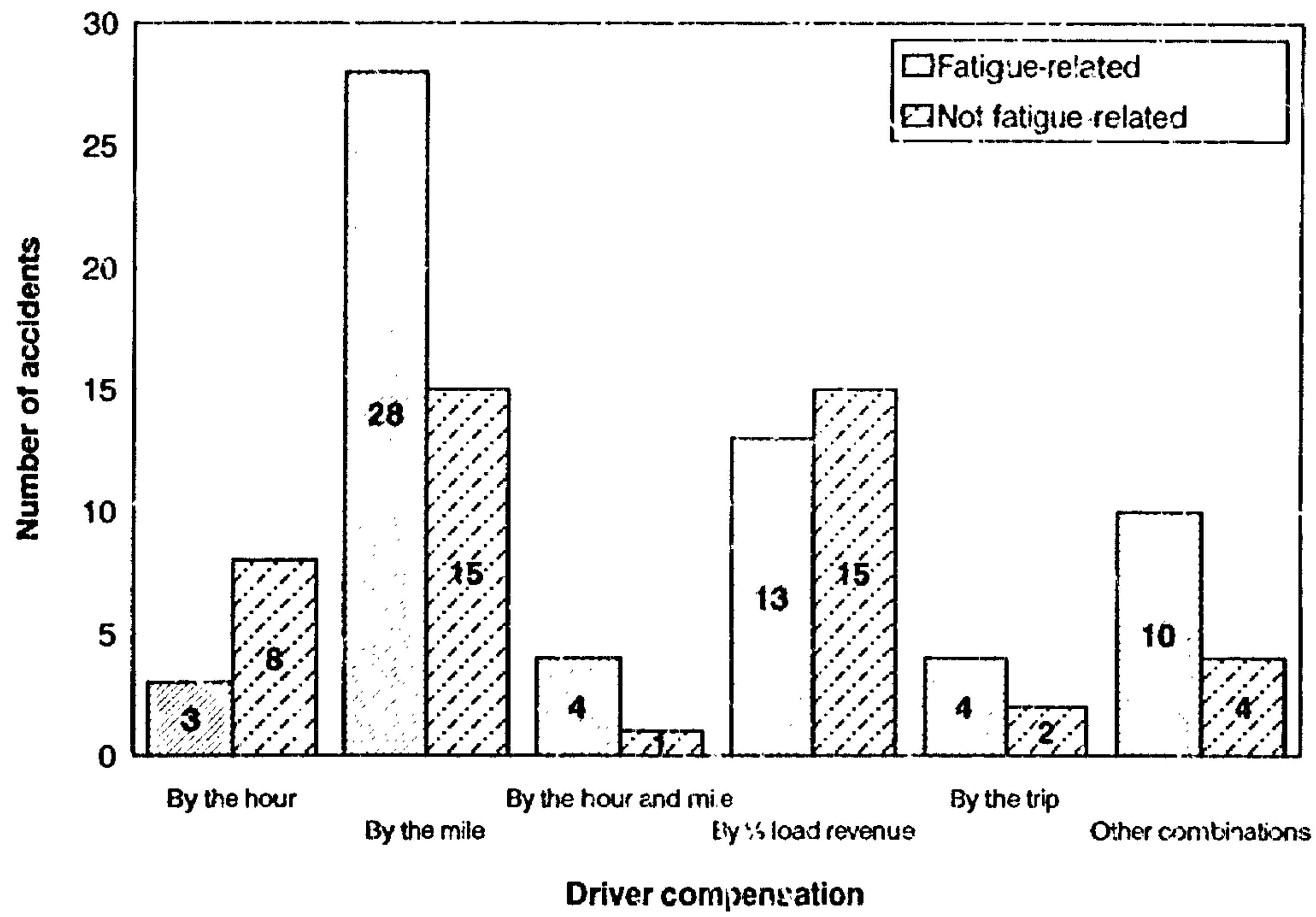


Figure 3.5—Number of accidents by driver compensation and fatigue involvement.

Alertness.—Drivers were asked to indicate on a seven-point scale how well they remembered the last 5 minutes of driving before the accident (1–very clearly to 7–not very clearly) and how alert they felt before the accident (1–fully alert to 7–completely exhausted). Drivers in fatigue-related accidents rated their memory as less clear and reported being less alert than drivers in nonfatigue-related accidents. However, these ratings should be viewed with caution because the majority of the drivers used ratings 1 through 3 on the memory and alertness scales.

Pay.—Forty-three of the 107 drivers reported that they were paid by the mile; 28 drivers said they were paid by a percent of the load revenue; and 11 drivers said they were paid by the hour. (See figure 3.5.) Some drivers said they were also paid extra for driving longer combination vehicles, hauling hazardous materials, and loading and unloading freight. Of the drivers who said they were paid by the mile, 65 percent had a fatigue-related accident (28 of 43). Of the drivers who reported being paid by a percent of the load revenue, 46 percent had a fatigue-related accident (13 of 28). Of the drivers who said they were paid by the hour (11), 3 had a fatigue-related accident.

The findings related to pay are generally consistent with the data from the Safety Board's 1990 study on fatal-to-the-driver heavy truck crashes.[41] In that study, data on trip compensation was available for 174 of the 182 truckdrivers. Of the 38 drivers paid by the mile, 16 were determined to be in a fatigue-related accident (42 percent). Of the 47 drivers paid by a percent of the load revenue, 15 were determined to be in a fatigue-related accident (32 percent). Of the 50 drivers paid by the hour, 9 were determined to be in a fatigue-related accident (18 percent).

Pay structure was also examined by long-haul (over 500 miles one way or away from home more than one night) versus short-haul (less than 500 miles one way, or local pick-up and delivery) trips. Nineteen of the long-haul drivers were paid by the mile, 16 were paid by percent load revenue, and 7 were paid by the hour. Twenty-four of the short-haul drivers were paid by the mile, 12 were paid by percent load revenue, and 4 were paid by the hour.

The Accident Trip

Fifty-seven of the 107 drivers were on a short-haul trip when the accident occurred; 50 were on a long-haul trip.[42] (See figure 3.6.) Of the drivers on long-haul trips, about 68 percent had a fatigue-related accident (34 of 50). Forty-nine percent of the short-haul drivers had a fatigue-related accident (28 of 57).

The majority of the accidents involved solo trips; however, of the nine accidents involving co-drivers, eight were fatigue-related. All of the co-drivers were on long-haul trips.

Fifty-six of the 107 drivers reported they had been away from home 1 or more days before the accident.[43] Seventeen of these drivers had been away 1 day, 31 had been away between 2 and 10 days, and 8 had been away between 11 and 50 days at the time of their accident. Sixty percent of the drivers involved in fatigue-related accidents (37 of 62) had been on the road away from home 1 or more days; 42 percent

---

[41] National Transportation Safety Board. Safety Study NTSB/SS-90/01.

[42] Of the 50 long-haul drivers, 38 had been away from home more than 1 night when the accident occurred.

[43] Almost 63 percent of the drivers (67 of 107) said that they do not typically return home every day/night to sleep. The number of drivers who reported that they had been away from home 1 or more days before the accident (56 of 107) does not equal the number of drivers considered to be on a long-haul trip (over 500 miles one way or away from home more than one night) (50 of 107) because a driver could be away 1 night and the trip could still be considered a short-haul trip if the driver returned home the next night. Also, some of the drivers who were on long-haul trips were on the first day of the trip when their accident occurred.

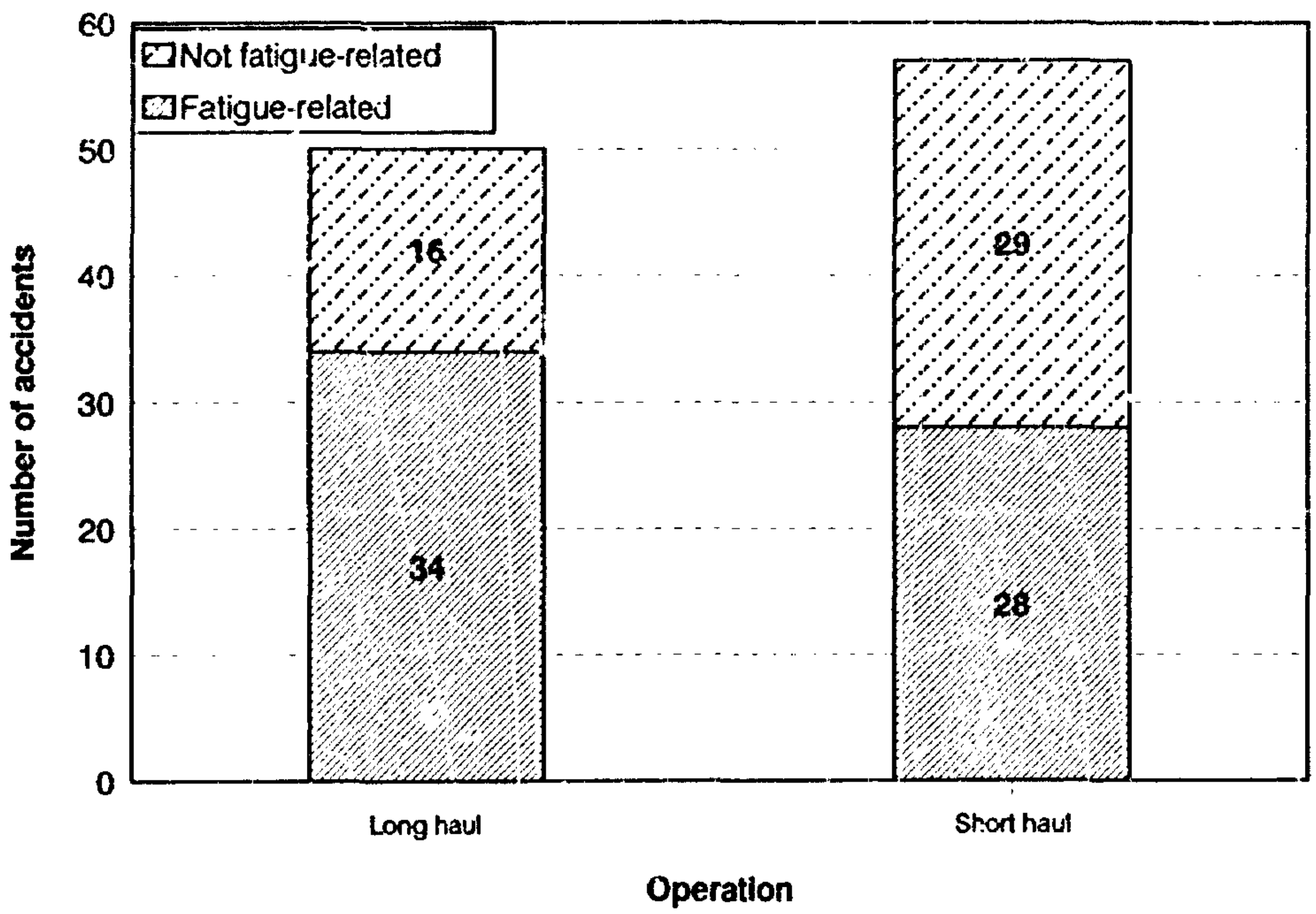


Figure 3.6--Number of accidents by type of trucking operation and fatigue involvement.

of the drivers in nonfatigue-related accidents (19 of 54) had been on the road away from home 1 or more days.

On the accident trip, the drivers had driven an average of 251 miles; 320 miles for the drivers in fatigue-related accidents and [illegible]4 miles for the drivers in nonfatigue-related accidents. Long-haul drivers had driven an average of 301 miles at the time of the accident; short-haul drivers had driven an average of 209 miles.

Characteristics of the Vehicles

The vehicles involved in the accident sample appeared to be representative by make. (See appendix B for the distribution by manufacturer, vehicle year, tractor and trailer type, and gross vehicle weight.) Eighty-three of the 107 vehicles in this sample were tractor semitrailers.

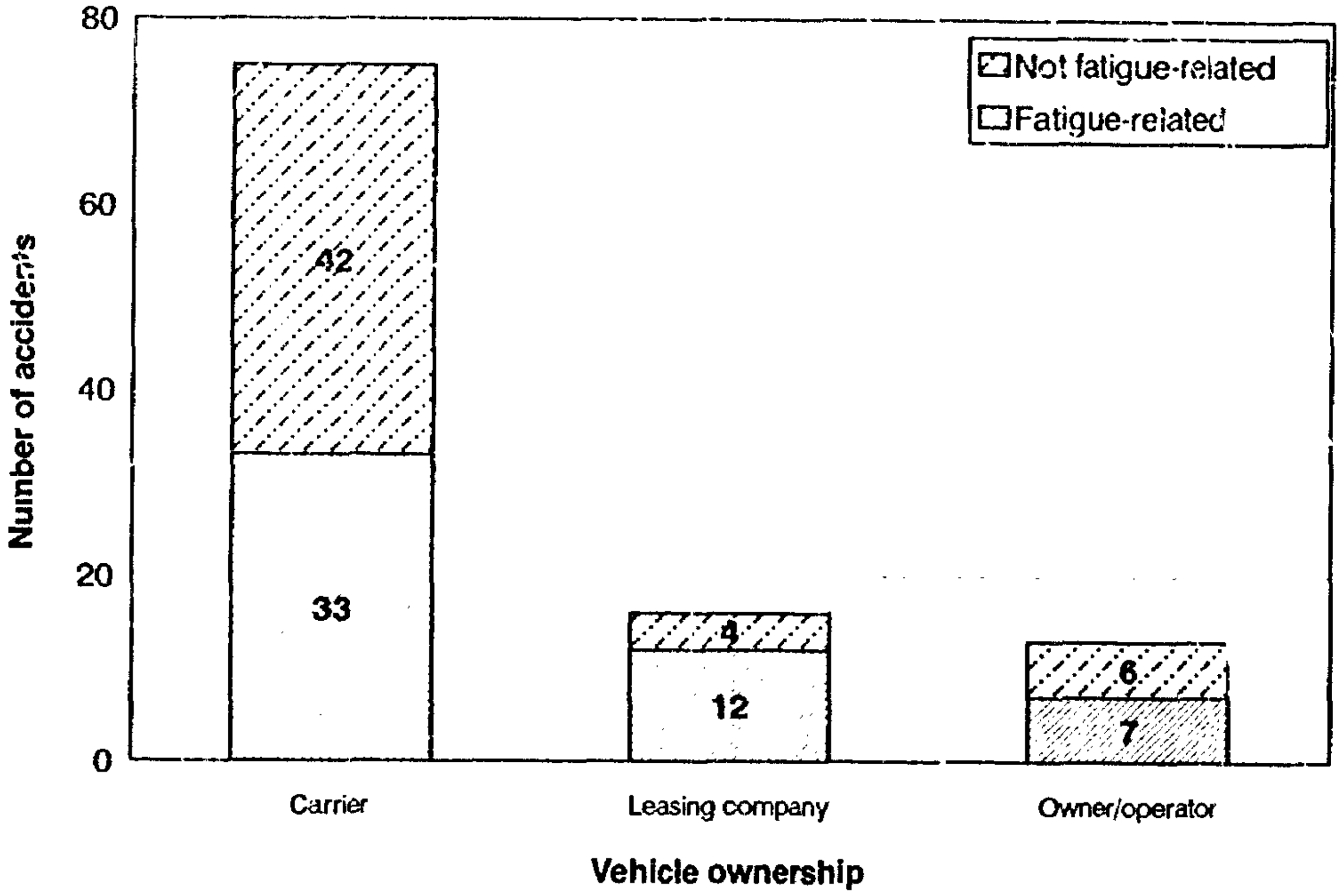


Figure 3.7—Number of accidents by vehicle ownership and fatigue involvement.

Seventy-six of the vehicles were equipped with sleeper berths. Fifty-three of the 103 drivers for whom information was available reported that they slept at home in their last sleep period before the accident, and 42 reported that they slept in the sleeper berth.[44] Six of the 42 drivers who reported that they slept in the sleeper berth in the last sleep period were on a trip with a co-driver. Of the remaining 8 drivers, 4 slept in a motel, 2 slept in the truck cab, and 2 slept in other locations. Of the drivers who slept at home, 51 percent were involved in a fatigue-related accident (27 of 53). Of the drivers who slept in their sleeper berth, 67 percent were involved in a fatigue-related accident (28 of 42). Both of the drivers who slept in the truck cab were in fatigue-related accidents. Eighty-eight of the 107 drivers reported that the quality of sleep in their last sleep period before the accident was good. Of the drivers involved in a fatigue-related accident, 82 percent of the drivers who slept at home (22 of 27) and 79 percent of the drivers who slept in their sleeper berth (22 of 28) reported that the quality of sleep was good or excellent.

Seventy-five of the 107 vehicles were owned by the carriers. (See figure 3.7.) Seventy-five percent of the vehicles owned by a leasing company were involved in fatigue-related accidents (12 of 16) compared to 55 percent for vehicles owned by the carrier (41 of 75) and 54 percent for those owned by the driver (7 of 13).

---

[44] For 4 of the 107 drivers, information was not available about the location of their last sleep period before the accident or the quality of that sleep period.

Motor Carriers

There were 104 different carriers and owner/operators involved in the 107 accidents. Drivers for 67 of the 105 companies for which information on carrier type was available (67 of 105) were engaged in interstate commerce. Of the 38 drivers engaged in intrastate commerce, 31 were subject to the U.S. Department of Transportation (DOT) safety regulations, including hours-of-service regulations.[45] The number of years the carriers had been in business ranged from less than 1 year to 90 years (the mean was 23 years).

The majority of employees hired by the companies were full time. There was wide variation in the number of drivers employed by the companies. Many of the companies have implemented hiring practices, such as minimum age requirements ranging from 20 to 30 years, previous driving experience (usually 2 years), probationary periods, preemployment drug testing, and State motor vehicle driver record checks (some carriers also check the National Driver Register maintained by the National Highway Traffic Safety Administration).

---

[45] Seven drivers were engaged in intrastate commerce operating within California; thus, they were subject to California rules. In California, truckdrivers may not drive after 12 hours of driving or 16 hours on duty. California allows a maximum of 80 hours on duty over 8 days (carriers of hazardous materials are subject to the Federal 60/70 hour rule). California participates in the Motor Carrier Safety Assistance Program, and under the guidelines that appear in 49 CFR 350, Appendix C, the Office of Motor Carriers has judged this variance to be "compatible" with the Federal rules.

Chapter 4

Driver Duty and Sleep Patterns

A total of 21 measures, all derived from detailed driver logs, were used to characterize drivers' patterns and amounts of duty and sleep in the 96 hours prior to the accident.[46] Tables 4.1 and 4.2 present summary statistics for these measures. (See appendix C for distributions of the duty and sleep measures.) Of the 107 drivers, the complete set of duty/sleep measures could not be computed for 20 drivers (based on the definitions provided in chapter 2, duty times could not be classified because they were interrupted by days off); hence, data from only 87 drivers were available for analysis (51 were involved in fatigue-related accidents, 36 were not). As would be expected, the driving and duty times of the 20 excluded drivers were less than those of the 87 drivers who had not had days off. Eleven of the 20 excluded drivers were involved in fatigue-related accidents, and the remaining 9 drivers were involved in nonfatigue-related accidents.

Discriminant Analysis

A multiple discriminant analysis[47] was performed to simultaneously evaluate the relationship of a set of 18 predictor measures[48] to the groupings of accidents established by investigators' determination of probable cause (fatigue-related and nonfatigue-related accidents). In the present case, discriminant analysis provides a means of simultaneously examining the capacity of the interrelated sleep, duty, and scheduling measures to classify an accident as either fatigue-related or nonfatigue-related. The combination of measures resulting from the application of the

---

[46] The majority of the single-vehicle accidents in the Safety Board's sample occurred between 2 and 8 a.m. (53 percent), and an even higher percentage of the accidents that were determined to be fatigue-related occurred during these same hours (75 percent). Time of day was not included as one of the 21 measures because of the inherent bias in the sample of cases; that is, single-vehicle accidents are likely to occur at night when traffic is light or sparse.

[47] A description of discriminant analysis can be found in the following publication: Tabachnick, B.G.; Fidell, L.S. 1989. Using multivariate statistics. 2nd ed. New York: Harper & Row. 746 p.

[48] Tables 4.1 and 4.2 describe 21 measures. However, because hours awake and hours asleep in the last 24 or 48 hours were complements of one another, only the time asleep measures were included in the analysis. Similarly, the scheduling measure of regular sleep/duty was not included because it is simply the complement of irregular duty/sleep. Thus, the set of predictors was reduced to 18 measures

Table 4.1—Means and standard deviations (SD) for number of hours on duty, and in driving and sleep periods before the accidents involving the 87 drivers for whom all data were available

Measure	Drivers in fatigue-related accidents (n = 51)		Drivers in nonfatigue-related accidents (n = 36)	
	Mean	*SD*	*Mean*	*SD*
Number of hours awake:				
In past 24 hours	17.1	2.9	14.7	2.0
In past 48 hours	32.3	4.5	29.9	3.5
Number of hours on duty:				
In past 24 hours	11.6	3.9	9.2	3.2
In past 48 hours	19.8	5.8	18.0	4.7
In most recent duty period	3.8	3.1	3.0	2.1
Number of hours driving:				
In past 24 hours	9.4	3.3	7.2	3.2
In past 48 hours	16.3	5.0	13.9	5.1
In most recent driving period	2.6	2.3	1.4	1.0
Number of hours slept:				
In past 24 hours	6.9	2.9	9.3	2.0
In past 48 hours	15.7	4.5	18.1	3.5
In most recent sleep period	5.5	2.5	8.0	2.6
Number of hours:				
Since last slept	8.9	7.8	6.0	4.0
Driving since last slept	5.2	3.9	3.0	2.3
On duty since last slept	6.2	4.9	4.2	2.8

Table 4.2—Number of fatigue-related and nonfatigue-related accidents, by duty/sleep pattern and other schedule-related measures, of the 87 drivers in the accident sample for whom data were available

Duty/sleep pattern and other scheduled-related measures of drivers involved in the accidents	Fatigue-related accidents		Nonfatigue-related accidents	
	Number	*Percent*	*Number*	*Percent*
Duty/sleep pattern:				
Irregular duty	11	21.6	7	19.4
Irregular sleep	1	2.0	2	5.6
Irregular duty/sleep	30	58.8	12	33.3
Regular duty/sleep	9	17.6	15	41.7
All schedules	51	100.0	36	100.0
Other schedule-related measures:[a]				
Inverted duty/sleep periods	9		1	
Split sleep pattern	[b]21		[c]4	
Exceeded hours-of-service limits[d]	21		4	

[a] These measures also applied to some of the 87 drivers with either regular or irregular duty/sleep patterns.

[b] Of the 21 drivers, 11 had a consistent pattern of split sleep, and 10 had a split sleep pattern for the accident trip.

[c] All 4 drivers had a split sleep pattern for the accident trip.

[d] Of the 25 drivers who exceeded the hours-of-service limits, 15 nad exceeded the limits at the time of their accident; 14 of those 15 drivers had a fatigue-related accident.

discriminant analysis to the Board's 87 accidents was able to correctly classify 94.4 percent of the nonfatigue-related accidents and 80.4 percent of the fatigue-related accidents—a very high rate of successful classification. (See appendix D for details.)

An advantage of using discriminant analysis is that it gives an indication of the relative contribution of each of the measures to accomplishing this classification. Table 4.3 lists the measures in the order of importance in predicting a fatigue-related accident for the sample of accidents and an indicator of that importance—the discriminant function loading.[49] The discriminant analysis clearly shows that the most important measures in predicting a fatigue-related accident in this sample are the duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep patterns.

As table 4.1 shows, drivers in fatigue-related accidents had an average of 5.5 hours of sleep in their last sleep period compared to an average of 8 hours of sleep for drivers who were not involved in a fatigue-related accident. Further, drivers in fatigue-related accidents had slept an average of 6.9 hours in the past 24 hours compared to 9.3 hours for drivers who did not have a fatigue-related accident. A review of the drivers for whom information was available on split sleep patterns found that 26 of 88 drivers (30 percent) had split sleep patterns.[50] The average length of sleep in the most recent sleep period for these 26 drivers was about 4 hours. The average length of sleep in the past 24 hours for the 26 drivers, however, was about 8 hours.

A second set of measures that play a role (but a lesser role) in predicting a fatigue-related accident are the duty-related measures including: exceeded hours-of-service limits, number of hours driving in the past 24 hours, number of hours on duty in the past 24 hours, duration of most recent driving period, and the number of hours driving since last sleep. Twenty-seven drivers in the total sample of 107 had exceeded the hours-of-service limits in the 96 hours preceding their accident; that is, they had driven more than 10 hours and/or been on duty more than 15 hours prior to taking their 8 consecutive hours off duty. Of those drivers who had exceeded the limits, about 82 percent (22 of 27) had a fatigue-related accident (see figure 4.1).[51]

---

[49] The discriminant analysis was statistically significant. (For details, see appendix D.)

[50] There was 1 driver for whom split sleep information was available even though his duty hours could not be classified (which caused him to be excluded from the discriminant analysis). Hence, there are 88 drivers for this specific analysis.

[51] Information about drivers exceeding the hours-of-service limits was considered in determining probable cause only as corroborating information when the physical evidence indicated a driver whose level of alertness was diminished.

Table 4.3—Standardized discriminant function loadings, by predictor measure, in order of each measure's contribution to discriminating between fatigue-related and nonfatigue-related accidents[a]

Measure	Loading
Duration of most recent sleep period (hours)	−0.524
Number of hours slept in past 24 hours	−.505
Split sleep pattern (yes, no)	.421
Exceeded hours-of-service limits (yes, no)	.376
Number of hours driving in past 24 hours	.359
Number of hours on duty in past 24 hours	.355
Duration of most recent driving period (hours)	.349
Number of hours driving since last slept	.349
Irregular duty schedule (yes, no)	.334
Number of hours slept in past 48 hours	−.314
Irregular duty/sleep schedule (yes, no)	.282
Number of hours on duty since last slept	.267
Inverted duty/sleep schedule (yes, no)	.256
Number of hours driving in past 48 hours	.255
Number of hours since last slept	.243
Irregular sleep schedule (yes, no)	.240
Number of hours on duty in past 48 hours	.183
Duration of most recent duty period (hours)	.149

[a] There were 107 cases in the accident sample; however, the discriminant function analysis was performed on 87 cases for which data on all the variables were available.

An obvious implication for drivers' exceeding the hours-of-service limits is the fewer number of hours available to obtain adequate sleep. The duration of the sleep period before the accident and the number of hours slept in the 24-hour period before the accident were significantly shorter for the drivers who had exceeded the duty hours than for those who had not (4.7 versus 7.2 hours, and 6.1 versus 8.3 hours, respectively). (See figure 4.2.)

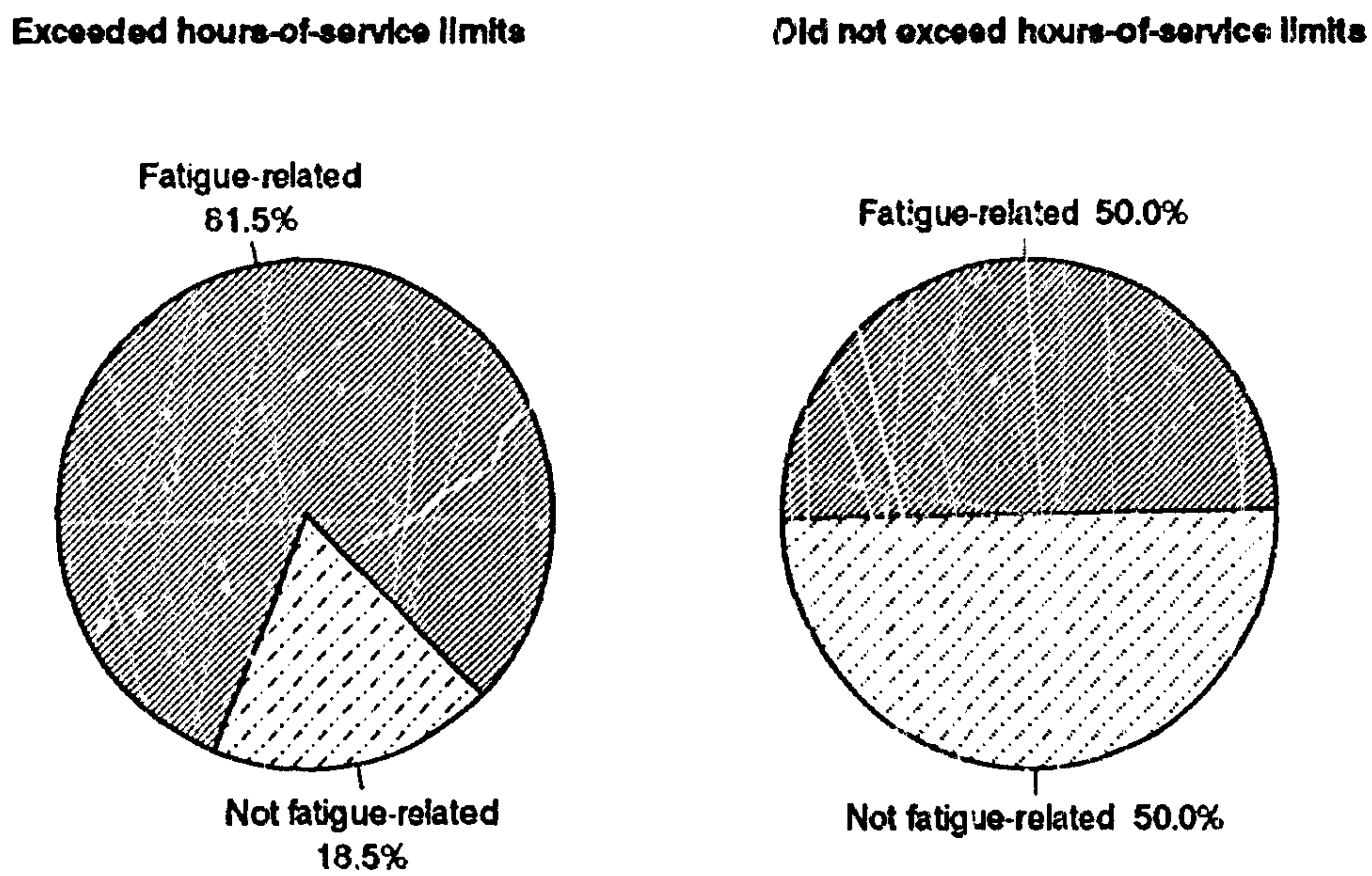


Figure 4.1—Percent of accidents for the 27 drivers who exceeded the hours-of-service limits and the 80 drivers who did not exceed the hours-of-service limits, by fatigue involvement.

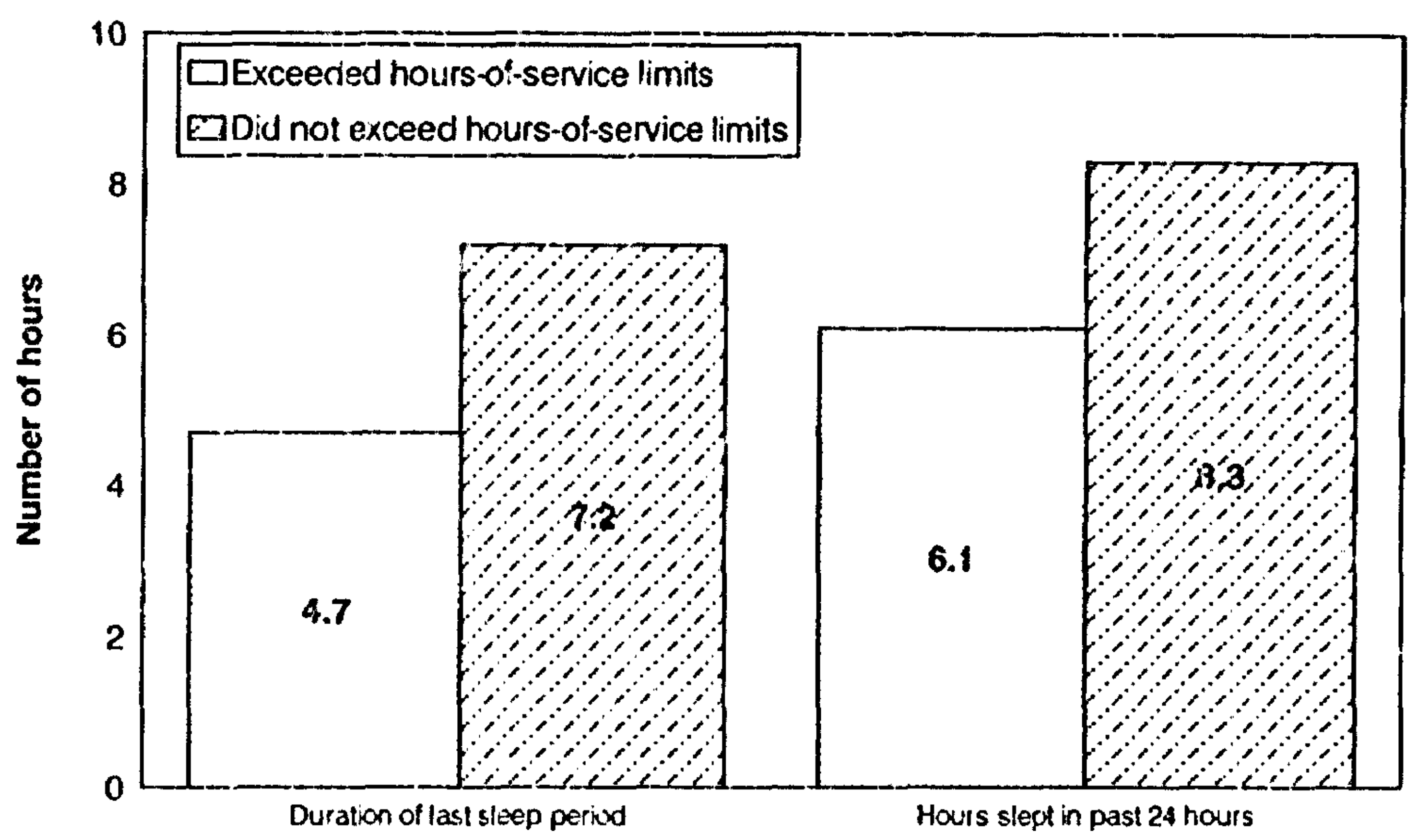


Figure 4.2—Number of hours slept in the last sleep period and past 24 hours for the 27 drivers who exceeded hours-of-service limits and the 80 drivers who did not exceed the hours-of-service limits.

Other Schedule-Related Measures

Two other measures in this sample were examined because of their potential effect on a truckdriver's duty and sleep times. These measures are irregular duty/sleep patterns, and inverted duty/sleep periods.[52] The irregular duty/sleep patterns and inverted duty/sleep periods played a less significant role in predicting a fatigue-related accident for this sample of cases; nevertheless, they can affect the ability of truckdrivers to obtain adequate sleep.

Irregular Duty/Sleep Patterns.—The data indicate that about 73 percent of the drivers for whom duty and sleep data were available (64 of 88) had irregular patterns of duty or sleep, or both irregular duty and sleep. About 67 percent of the drivers with irregular patterns had fatigue-related accidents (43 of 64) whereas about 38 percent of drivers with regular patterns had fatigue-related accidents (9 of 24).[53] (See figure 4.3.)

The number of hours slept during the most recent sleep period differed between drivers with regular and irregular patterns by an average of 1.6 hours. Drivers with irregular patterns averaged only 6.1 hours of sleep whereas drivers with regular patterns averaged 7.7 hours of sleep during the most recent sleep period. The number of hours slept in the past 24 hours was similar for drivers with regular and irregular schedules (7.7 versus 7.9 hours).

Inverted Duty/Sleep Periods.—Seventeen of the 107 drivers had inverted their duty/sleep periods on the accident trip; that is, the accident occurred at a time when on the previous day the driver had been sleeping. All but one of these drivers (94 percent) had a fatigue-related accident. The driver that did not have a fatigue-related accident had a mechanical failure on his truck.

The mean duration of the most recent sleep period for the 16 drivers with inverted duty/sleep periods who had a fatigue-related accident was 6.3 hours compared to 7.9 hours for the 44 drivers who did not have either an inverted duty/sleep period or a fatigue-related accident. (The one driver with an inverted schedule

---

[52] See chapter 2 and table 2.1 for definitions of irregular and inverted duty/sleep patterns.

[53] The nine cases in which the driver had no irregular duty/sleep patterns but had a fatigue-related accident were examined to determine what factors may have been associated with the drivers' fatigue. In six of these cases, some aspect of the drivers' duty/sleep pattern changed only in the 24-hour period before the accident. Because the study criteria required two consecutive changes in the duty hours or sleep periods to be considered an irregular pattern, these six cases were considered regular patterns. The changes included lack of sleep (four cases) and starting work 1.5 hours or more earlier than normal (two cases). The remaining three cases involved a driver with diagnosed sleep apnea, a driver who had started a new job that required him to start driving about 4 a.m., and a nightshift worker who, based on the physical evidence, was not alert.

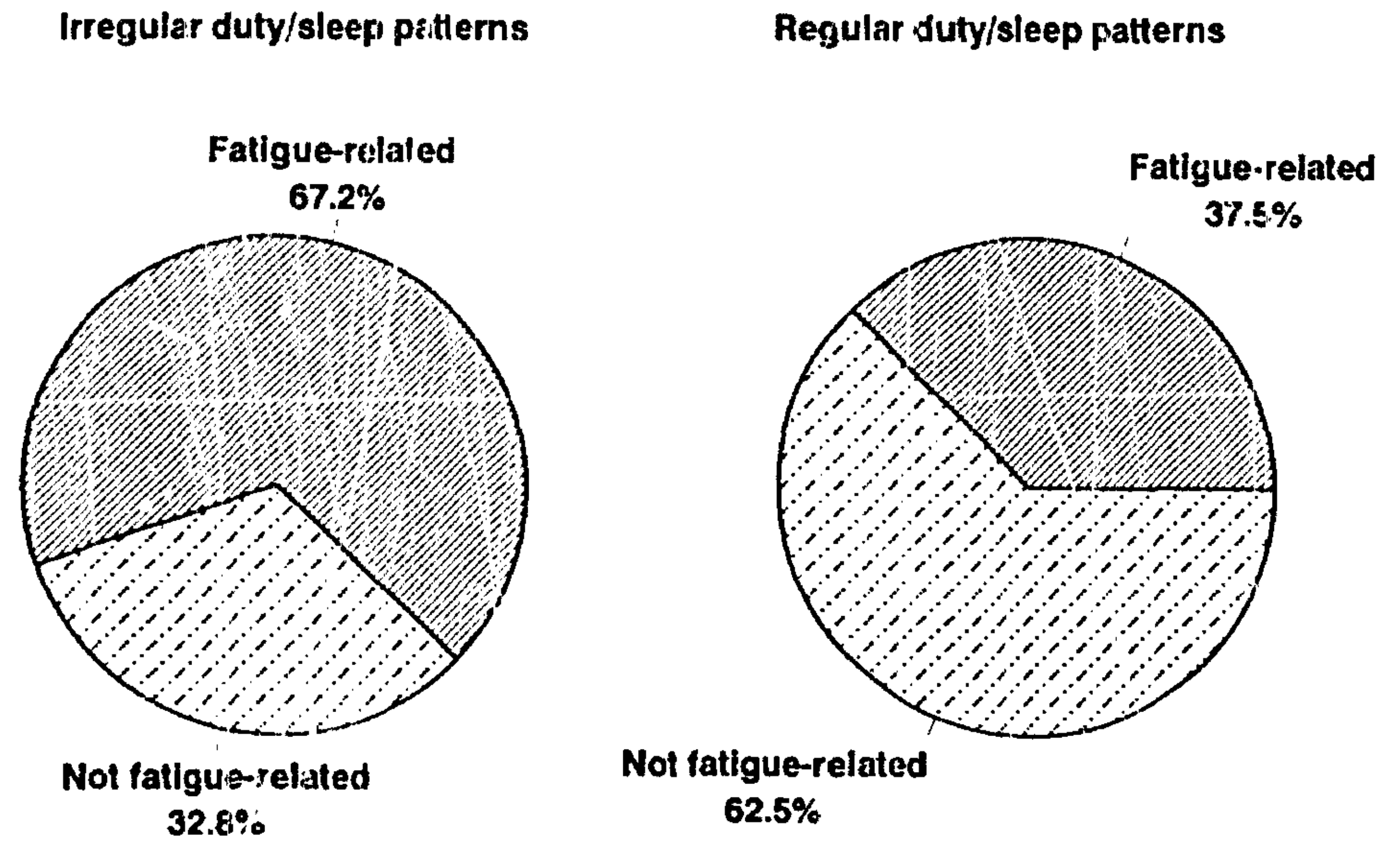


Figure 4.3--Comparison of duty/sleep patterns for the 45 drivers with regular patterns and the 43 drivers with irregular patterns, by fatigue involvement. The 19 drivers for whom duty/sleep information was missing are not included in this comparison.

who did not have a fatigue-related accident had slept 10 hours in his last sleep period and in the 24 hours prior to the accident.) The average number of hours slept in the 24 hours prior to the accident was significantly shorter for the 16 drivers with inverted duty/sleep periods who had a fatigue-related accident than for those drivers without inverted periods or a fatigue-related accident (5.2 hours versus 7.9 hours). (See figure 4.4.) In addition, the mean number of hours awake since the driver had last slept was more than twice as long for the drivers with inverted duty/sleep periods who had a fatigue-related accident (14.2 hours) than for those without an inverted schedule who did not have a fatigue-related accident (6.2 hours). The data suggest that the amount of sleep obtained in the most recent sleep period may be a more important measure than a schedule inversion in predicting a fatigue-related accident and may explain why the inverted duty/sleep pattern did not load higher on the discriminant analysis.

Of the 17 drivers with inverted duty/sleep periods, the accidents of 14 drivers occurred between midnight and 6:30 a.m., and 13 of these accidents were fatigue-related. The other three accidents, all of which were fatigue-related, occurred at 10:45 a.m., 9:30 p.m., and 11 p.m. Research has shown that nightshift work

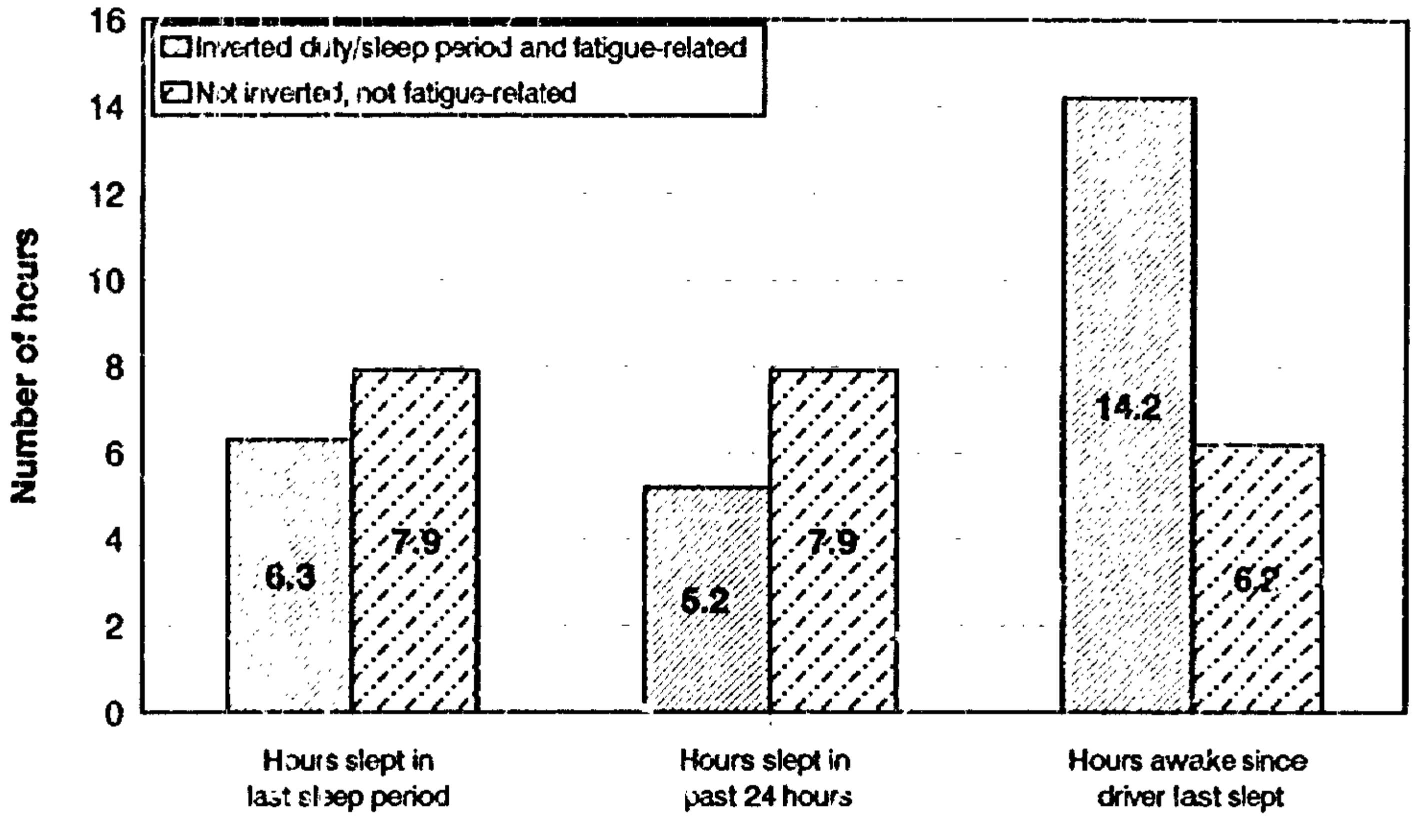


Figure 4.4—Number of hours slept in the last sleep period and in the past 24 hours, and number of hours awake since the driver last slept for the 17 drivers with inverted duty/sleep periods and the 90 drivers without inverted periods.

schedules in general are more tiring for workers than dayshift work schedules.[54] Nightshift workers usually get less uninterrupted sleep each day, a situation that creates a sleep debt that workers attempt to repay by sleeping longer periods of time on their days off.[55] Also, workers who invert their schedules may experience difficulty in falling asleep during the day.[56]

Drivers who are driving during early morning hours following an inversion in their duty/sleep periods would be more vulnerable to reduced alertness and reduced performance ability.[57] Research has shown that night shift workers who change to a day shift schedule (and night sleeping) on their days off will exacerbate the cumulative fatigue which will then affect their work on subsequent night shift

---

[54] Tepas, D.I.; Monk, T.H. 1987. Work schedules. In: Salvendy, G., ed. Handbook of human factors. New York: Wiley-Interscience Publications: 828-832.

[55] McDonald (1984, p. 18-_o).

[56] (a) McDonald (1984). (b) Åkerstede, Torbjörn. 1987. Sleepiness as a consequence of shift work. Sleep. 11(1): 17-34.

[57] Tepas, Donald I. 1982. Work/sleep time schedules and performance. In: Webb, Wilse B., ed. Biological rhythms, sleep, and performance. Chichester; New York: John Wiley & Sons: 175-204. Chapter 7.

schedules.[58] The inversion of a duty/sleep period followed a day off in 2 of the 17 cases and 2 days off in 3 additional cases. The mean number of hours awake in the 24- and 48-hour periods preceding the accident was significantly longer for the drivers whose duty/sleep periods had been inverted (18.53 hours and 33.22 hours, respectively) than for those whose duty/sleep periods had not been inverted (15.79 hours and 31.04 hours, respectively). These results are expected; an inversion often creates a situation in which drivers are not only working at a time when they were sleeping the previous day, but were awake and doing other normal daily duties before they were working. This situation can result in greater-than-normal awake time when schedules become inverted. The differences are greatest during the time period immediately preceding the accident. These differences tend to diminish as the number of hours and days preceding the accident increase. The leveling off occurs because the longer time period preceding the accident includes off-duty days during which drivers tend to catch up on their sleep.[59] In summary, the data indicate that driving at night with a sleep deficit is far more critical in terms of predicting fatigue-related accidents than simply nighttime driving.

Long-Haul versus Short-Haul Operations.—The type of truckdriving operation has been assumed possibly to influence, or be confounded with, the distinction between drivers with regular schedules and those with irregular schedules. That is, long-haul operations are often assumed to be associated with irregular schedules. Consequently, a second discriminant function analysis was performed to assess the discriminability of groups formed on the basis of long- or short-haul driving assignments. The same set of 18 measures were analyzed for the 87 cases that had no missing data for any of the variables. The discriminant analysis was able to discriminate clearly between the long- and short-haul operations. The combination of measures resulting from the application of the discriminant analysis to the Board's 87 accidents was able to correctly classify 87 percent of the long-haul drivers and 70.7 percent of the short-haul drivers—a high rate of successful classification. (See appendix D for details of analysis.)

The results of the analysis for this sample support the view that long-haul operations are associated with irregular schedules. (See table 4.4.) The three measures that represent dichotomous (yes/no) indicators of the irregularity of sleep, duty, and combined sleep and duty have the highest loadings and, as expected, are the primary measures separating long- from short-haul drivers. It is interesting to note that the measure of duration of the most recent sleep period, which was the most important variable in discriminating between fatigue-related and nonfatigue-related accidents, ranked very low on this analysis. Thus, although the quantity of sleep was the most important measure in predicting a fatigue-related accident, it does not discriminate between long-haul and short-haul operations. In fact, 68 percent of long-haul drivers and 49 percent of short-haul drivers in this sample had fatigue-

---

[58] Monk, T.H.; Wagner, J.A. 1989. Social factors can outweigh biological ones in determining night shift safety. Human Factors. 31(6): 721-724.

[59] McDonald (1984, p. 18).

Table 4.4—Standardized discriminant function loadings, by predictor measure, in order of each measure's contribution to discriminating between long-haul and short-haul assignments[a]

Measure	Loading
Irregular sleep schedule (yes, no)	0.651
Irregular duty schedule (yes, no)	.642
Irregular duty/sleep schedule (yes, no)	.618
Number of hours slept in past 48 hours	.350
Split sleep pattern (yes, no)	.331
Number of hours driving in past 48 hours	.315
Exceeded hours-of-service limits	.271
Duration of most recent driving period (hours)	.230
Number of hours driving in past 24 hours	.219
Number of hours driving since last slept	.198
Number of hours slept in past 24 hours	.184
Duration of most recent duty period (hours)	−.137
Number of hours since last slept	.098
Number of hours on duty since last slept	.096
Duration of most recent sleep period (hours)	−.091
Inverted duty/sleep schedule (yes, no)	.056
Number of hours on duty in past 48 hours	.031
Number of hours on duty in past 24 hours	.021

[a] There were 107 cases in the accident sample; however, the discriminant function analysis was performed on 87 cases for which data on all the variables were available.

related accidents. The Safety Board could not determine if irregularity of duty/sleep patterns, per se, would lead to fatigue; the drivers with irregular patterns in the Board's study did not receive sufficient sleep in their most recent sleep period. The Board, consequently, did not have the opportunity to examine drivers who consistently received 8 or more hours of daily sleep but began their duty and/or sleep at various (irregular) times over a period of days. The Board believes that this issue is worthy of pursuit. The Safety Board also notes that split sleep patterns ranked fifth in order of importance in discriminating between long-haul and short-haul operations.

Methodological Considerations

The computation of the measure of amount of sleep in the last 24 hours could, of course, arbitrarily truncate sleep periods that had begun before the 24-hour period (the driver's sleep period had started more than 24 hours prior to the accident). Examination of driver logs revealed that 33 of the 107 drivers had been asleep at the 24th hour prior to the accident. The distribution of lengths of these sleep periods in relation to the 24th hour are shown in figure 4.5. Rerunning the discriminant analysis with the amount of sleep in the last 30 hours substituted for the amount of sleep in the last 24 hours produced the same result as the original analysis. The Board also notes that a cutoff of 30 hours for this measure would have truncated the sleep periods of 41 drivers.

The evidence used for a probable cause determination of fatigue involvement in eight of the cases was information from the driver's 96-hour duty/sleep history that suggested a reduced state of alertness or sleep loss and eight cases in which fatigue was a contributing factor. There was concern that the discriminant function classification was being influenced by the duty/sleep time measures used in determining the probable cause of the 16 cases in which the probable cause determination was not based primarily on the drivers' statement of falling asleep or clear physical evidence of such; therefore, the Safety Board reran the discriminant function analysis without these 16 cases. The results of this analysis were the same, which indicates that the discriminant function classification was not biased by these 16 cases.

The Safety Board acknowledged in chapter 2 that the definitions of duty and sleep, as defined in this study, are arbitrary and that there may be other ways to define these terms. Because of concern that defining the start of a new duty period after an off-duty interval as short as 1 hour might distort the findings, the Safety Board redefined the duty period as a period (driving or on duty not driving) that was not interrupted by more than 2 hours of off-duty time. Redefining this measure influenced only three cases, and rerunning the discriminant analysis produced virtually the same result as the original analysis.

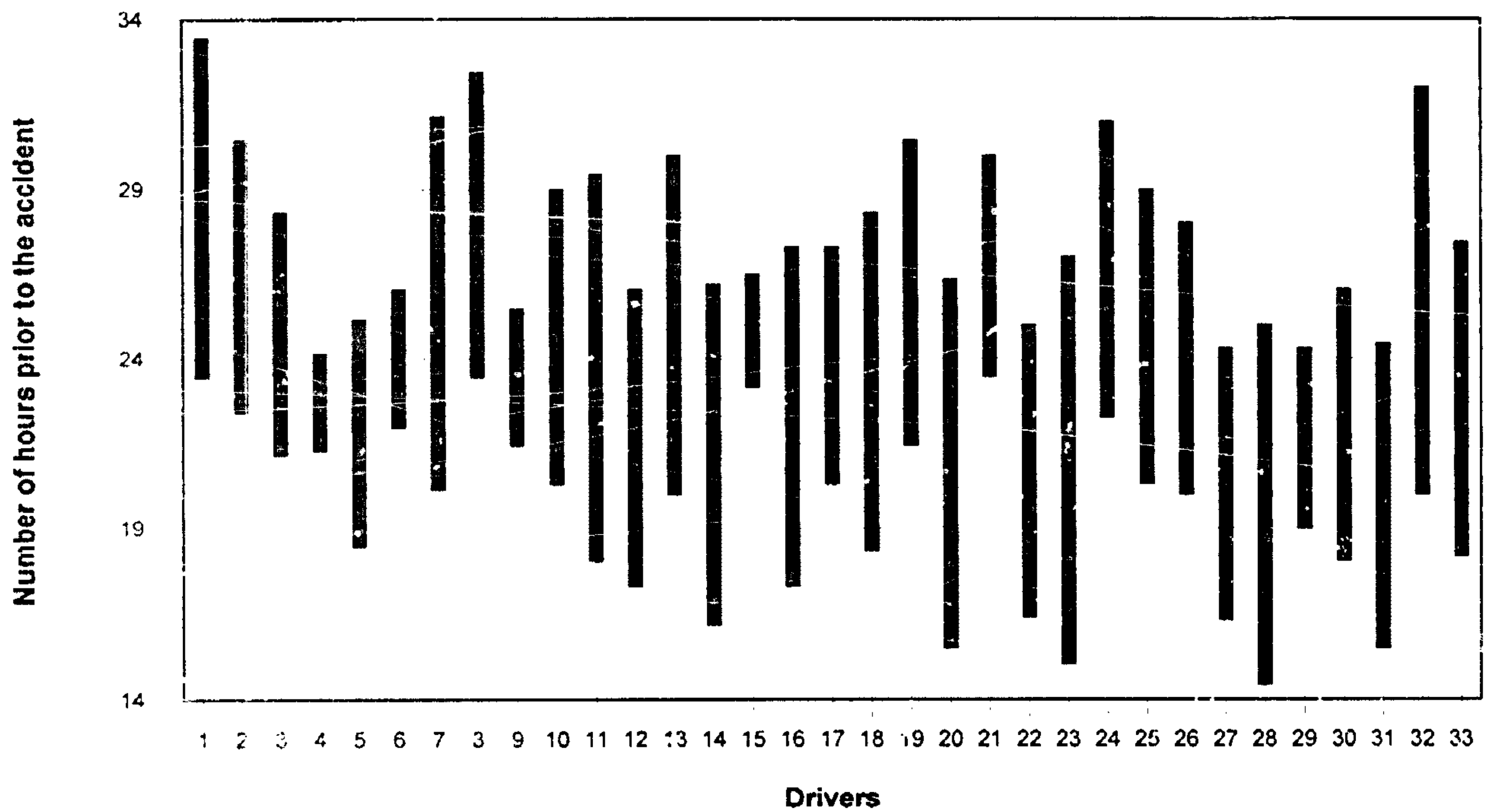


Figure 4.5—Sleep periods for the 33 drivers who had been sleeping at the 24th hour prior to their accident.

Chapter 5

Discussion

The results of the discriminant analysis indicate that the most critical measures in predicting fatigue-related accidents in the Safety Board's sample are the duration of the most recent sleep period, the amount of sleep in the past 24 hours, and split sleep patterns. It is not surprising that sleep factors rated high in this analysis given the results of extensive scientific research in this area. However, the Board believes that it is noteworthy in this unique sample of actual accidents that factors that affect the ability to obtain adequate sleep, such as irregular duty/sleep and inverted schedules (which are often assumed to be closely associated with fatigue), ranked well below the factors that affect the quantity and quality of sleep.[60]

The truckdrivers in fatigue-related accidents in this sample obtained on average 5.5 hours of sleep in the last sleep period prior to the accident. This is 1.4 hours less than the 6.9 hours they reported needing to feel rested and 2.5 hours less than that obtained by drivers in nonfatigue-related accidents (8.0 hours of sleep in the last sleep period). The findings further indicate that the truckdrivers involved in fatigue-related accidents obtained about 2.4 hours less sleep in the 24-hour period before the accident than the drivers not involved in fatigue-related accidents (6.9 hours compared to 9.3 hours).

The data in table 4.1 indicate that the mean time awake, but not on duty, for the drivers in the fatigue-related accidents was about 5.5 hours. This suggests that these drivers could have readily attained more than the mean of 5.5 hours of sleep during the last sleep period prior to the accident. However, the timing of the awake period may not have fit with the driving schedule to permit 8 hours continuous sleep in the last sleep period. Further, the drivers have a need to attend to family duties and other responsibilities. The fact that drivers in nonfatigue-related accidents also were awake about 5.5 hours while off duty (but still attained 8 hours sleep in the most recent sleep period prior to the accident) suggests that 5.5 hours is not an unreasonable period of time to be allocated to such needs. It appears, therefore, that if the driving or on-duty time is pushed to the maximum hours allowed, drivers will reduce the amount of time for sleep rather than the time needed to accomplish other duties and responsibilities.

---

60 Although the Safety Board examined single-vehicle accidents, there is no reason to believe that the factors that were associated with fatigue-related single-vehicle accidents would be any different in other kinds of accidents. The Board believes, therefore, that the results of this study can be generalized to the trucking population as a whole.

The HOS regulations currently require drivers to be off duty for a minimum of 8 consecutive hours after reaching the maximum number of hours allowed: 10 hours driving and/or 15 hours on duty. (Drivers are allowed to reach 60 on-duty hours in 7 days or 70 hours in 8 days.) In drafting these regulations in 1937, the Interstate Commerce Commission (ICC) wrote:

> It is obvious that a man cannot work efficiently or be a safe driver if he does not have an opportunity for approximately 8 hours sleep in 24. It is a matter of simple arithmetic that if a man works 16 hours per day he does not have an opportunity to secure 8 hours' sleep. Allowance must be made for eating, dressing, getting to and from work, and the enjoyment of the ordinary recreations.[61]

The need for adequate sleep and the effect of inadequate sleep on performance is well documented in the scientific literature (see footnotes 10 through 28, and appendix A). The Board's past safety studies and accident investigations have also highlighted fatigue as a factor in operator performance. The recurring role of fatigue in transportation accidents prompted the Safety Board 6 years ago to recommend that the Secretary, U.S. Department of Transportation:

> Expedite a coordinated research program on the effects of fatigue, sleepiness, sleep disorders, and circadian factors on transportation system safety. (I-89-1)
>
> Develop and disseminate educational material for transportation industry personnel and management regarding shift work; work and rest schedules; and proper regimens of health, diet, and rest. (I-89-2)
>
> Review and upgrade regulations governing hours of service for all transportation modes to assure that they are consistent and that they incorporate the results of the latest research on fatigue and sleep issues. (I-89-3).

The three safety recommendations are currently classified "Open—Acceptable Response." In response to recommendation I-89-1, the DOT formed the DOT Human Factors Coordinating Committee, comprising representatives from each of the modal agencies, who regularly brief the Safety Board on the progress of the committee and action taken by each modal agency to address these recommendations. According to these briefings, some dissemination of useful information is occurring, as recommended in I-89-2. With respect to I-89-3, the Board recognizes the long-term nature of this recommendation. On October 21, 1994, a representative of the FHWA briefed the Safety Board on the status of the fatigue research being sponsored by the FHWA.

---

[61] 3 M.C.C. 673, December 29, 1937.

The FHWA has several ongoing and planned studies to address fatigue and commercial truckdriving. The purpose of one study that is being conducted in conjunction with the Walter Reed Army Institute of Research is to determine the number of hours, or range of hours, a driver needs to recover from a fatigued condition after operating a commerical motor vehicle. The first phase of this study will collect data on sleep/wake cycles from 25 over-the-road and 25 local drivers using activity monitors (actigraphs). The second phase will be a laboratory study of commercial drivers who will operate a personal computer-based driving simulator and take computer-based performance tests. The results of this study are not expected until late 1997. Another FHWA study, which was begun almost 5 years ago in conjunction with the Essex Corporation and the American Trucking Associations' Trucking Research Institute (TRI), is in the final analysis stage. This study was conducted to measure loss of alertness and the onset of fatigue among commercial vehicle operators. According to the FHWA, the overall intent of this research is (1) to provide a technically sound basis for evaluating the hours-of-service regulations and (2) to develop countermeasures for reducing fatigue and increasing driver alertness. Data have been collected on testing for four different driving/operating conditions. Forty drivers from two U.S. carriers and 40 drivers from one Canadian carrier participated in the project.[62] The data collection was completed in December 1993. A survey of 500 drivers will be conducted in late 1994. A final report on this project is expected in May 1995.

Several other studies on truckdriver fatigue are being conducted by the FHWA and, in particular, its Office of Motor Carriers (OMC). The OMC is currently studying commercial driver rest stop requirements to determine what public rest area services and needs are desired by commercial truckdrivers and how well the current system meets these needs. The FHWA and the TRI are evaluating in-terminal and in-vehicle testing technologies and devices for their ability to accurately and reliably determine the fitness of commercial motor vehicle operators to safely drive their vehicles. The FHWA and the TRI are also undertaking a study to obtain a relatively precise estimate of the prevalence of sleep apnea in a population of high risk truckdrivers and to estimate the level of sleep apnea at which driving impairment becomes important.[63] In response to the Intermodal Surface Transportation Efficiency Act, the FHWA and the National Highway Traffic Safety Administration are co-sponsoring a study to address the effects of multiple-trailer combination vehicle operation on driver stress and fatigue.

The Safety Board commends the FHWA and the other modal administrations for their efforts to address the issue of fatigue in transportation. The Board recognizes the importance of laboratory studies and controlled driving experiments and their contributions toward enhancing the general understanding of the

---

[62] Hours-of-service rules in Canada permit up to 13 hours of driving. One aspect of the study is to evaluate the effects of driving longer hours.

[63] The Safety Board's sample of 107 accidents included one driver with diagnosed sleep apnea, case 53.

physiological mechanisms underlying fatigue, the performance decrements that accompany fatigue, and improved strategies for maintaining alertness. Notwithstanding its support for the ongoing research, the Safety Board believes that the results of this study of actual accidents provides concrete evidence of the measures that affect fatigue in the accident environment and offers a unique opportunity to develop appropriate countermeasures. Studies of subjects in a laboratory environment or controlled driving experiments cannot provide such evidence of the factors that lead to fatigue-related accidents (or any accidents for that matter). Accident investigations provide a much more valid body of information on which to base sound transportation safety policy decisions than what can be obtained in controlled or laboratory studies. This set of accidents provides the necessary data, and the results of this accident-based study clearly demonstrate the need to obtain adequate sleep to avoid the effects of fatigue when operating transportation vehicles.

Research indicates that the amount of sleep needed varies on an individual basis: "...for some it is 5 to 6 hours a night, for others it is...7 or 8 hours, and for still others it is 9 to 10 hours."[64] The Safety Board recognizes that all truckdrivers do not need 8 hours of sleep. However, responsible public policy dictates that drivers of heavy trucks be able to obtain adequate sleep between work assignments. Implementation of this policy, in the form of Federal regulations or industry procedures and practices, cannot generally address drivers on an individual basis. Thus, implementation of this policy must address the norm, which research has determined to be 8 hours,[65] a fact noted by the ICC in 1937. The results of this study support the need by the "average" driver for 8 continuous hours of sleep.

The Board has addressed the issue of adequate rest periods in various modes of transportation. Recently, the Board addressed this issue in the aviation mode. Current regulations require a minimum rest period of 10 hours for a pilot scheduled to fly an 8- to 9-hour flight. The regulations also allow for providing flightcrews with less than the required rest period in exchange for compensatory rest later. For example, if the scheduled flight time for a pilot is 8 to 9 hours, the rest period before duty may be reduced from 10 to 8 hours if the rest period following duty is increased to 11 hours.

---

[64] Dinges, D.F. 1984. The nature and timing of sleep. Transactions & Studies of the College of Physicians of Philadelphia. Ser.5:6(3): 177-206 (p. 198).

[65] (a) Carskadon, M.S.; Dement, W.C. (1994). (b) Carskadon, Mary A., ed. 1993. Encyclopedia of sleep and dreaming. New York: Macmillan Publishing Company.

If the scheduled flight time is:	The minimum rest period in the 24 hours before duty is:	Which may be reduced to:	If the rest period following duty is increased to:
< 8 hours	9 hours	8 hours	10 hours
8-9 hours	10 hours	8 hours	11 hours
≥ 9 hours	11 hours	9 hours	12 hours

The intent of the reduced rest provisions was to provide carriers more flexibility with flightcrew schedules to accommodate extended duty days that result from unforeseen operational delays. However, the current reduced rest provisions allow carriers to establish schedules that result in reduced rest, and many airlines routinely take advantage of the provisions when scheduling their flightcrews rather than using the provisions for unforeseen circumstances, as originally intended. Following its investigation of a commuter aircraft accident in Brunswick, Georgia, on April 5, 1991,[66] the Safety Board recommended that the Federal Aviation Administration:

> Issue an Air Carrier Operations Bulletin (ACOB) directing Principal Operations Inspectors to clarify with their operators that the intent of 14 CFR Section 135.265 is not to routinely schedule reduced rest, but to allow for unexpected operational delays, and to require compliance with the intent of the regulation. (A-92-28)

In its recent study on commuter airline safety,[67] the Board classified this recommendation "Open—Unacceptable Response" and expressed disappointment that important issues concerning flightcrew scheduling and rest remain unresolved after 2 years. In that study, the Board reiterated its position that "...rest should be defined as time available for restful sleep, and minimum rest periods should provide the opportunity for adequate sleep, taking into account time needed for travel to and from rest facilities and for attending to nourishment and personal hygiene"—again, a point made by the ICC in 1937.

In some countries, drivers are not only required to rest for longer periods of time each day, but if they choose to break their rest period into smaller blocks, the total cumulative rest period is increased. The rule is meant to compensate for the poorer quality of rest received when small, nonconsecutive rest periods are substituted for one long (consecutive) rest period. For example, in Europe most drivers engaged in international road transport are required to have a daily rest

[66] National Transportation Safety Board. 1992. Atlantic Southeast Airlines, Inc., flight 2311, uncontrolled collision with terrain; an Embraer EMB-120, N270AS, Brunswick, Georgia, April 5, 1991. Aircraft Accident Report NTSB/AAR-92/03. Washington, DC.

[67] National Transportation Safety Board. 1994. Commuter airline safety. Safety Study NTSB/SS-94/02. Washington, DC.

period of 11 consecutive hours. Their rest period may be broken into two or three separate periods during the 24-hour period; however, one of the periods must be at least 8 consecutive hours. Further, if a driver chooses to break up his or her rest period, the minimum length of the total rest is increased to 12 hours.[68]

The Safety Board recognizes that regulations cannot assure that adequate sleep will be obtained. Nevertheless, the regulations can and must provide the opportunity to obtain an adequate amount of rest. However, the 8-hour off-duty requirement in the current regulations does not do so because it does not provide time for travel, eating, personal hygiene, and recreation. Further, depending on various factors, including the time of day, a driver may not be able to fall asleep immediately at the beginning of the 8-hour off-duty period. Because the results of this accident sample are unlikely to be substantially enhanced by any further research, these results provide a solid basis for sound policy decisions. The Board also recognizes that the inadequate sleep obtained may not be directly related to the 8-hour off-duty requirement in the HOS regulations. However, in the Safety Board's view, a minimum standard that does not provide for at least 8 hours of sleep is not responsible public policy and could be construed as condoning less than 8 hours of sleep as adequate, when the time needed for eating, hygiene, and recreation is considered. Therefore, the Board believes that within 2 years the FHWA should complete rulemaking to revise 49 CFR 395.1 to require sufficient rest provisions to enable drivers to obtain at least 8 continuous hours of sleep. This revision would satisfy the highway portion of the intermodal Safety Recommendation I-89-03.

Given the results of the latest research and studies on fatigue and sleep issues, the Board believes that steps can be taken now to provide truckdrivers with the opportunity to obtain 8 continuous hours of sleep and that the trucking industry can take a lead role in this effort. Therefore, the Safety Board believes that the trucking industry should incorporate into its scheduling practices and procedures the results of the latest research on fatigue and sleep issues, particularly that an 8-hour continuous sleep need is the norm. The Safety Board believes that current scheduling practices can accommodate a change in the rest period without resulting in undue economic hardships. Although an increase in the rest period may limit, to some extent, the flexibility in scheduling of some carriers, the Board has no evidence that an increase in the amount of off-duty time would significantly change the way they schedule their deliveries or require changes in the locations of terminals. The Safety Board believes that the majority of trucking companies currently comply with the hours-of-service regulations. Further, the truckdrivers involved in the nonfatigue-related accidents in this study were typically on duty 9 hours a day. These drivers had sufficient time to obtain adequate sleep; in fact, they obtained 8 continuous hours of sleep in their last sleep period.

---

[68] European Agreement concerning the work crews of vehicles engaged in International Road Transport (AETR), entered into in Geneva on July 1, 1970, Amendment 2 and Protocol of Signature (Amendment 2 went into effect on April 24, 1992.)

The Safety Board recognizes that providing the opportunity to obtain adequate sleep will not assure that drivers actually obtain that sleep. The ICC recognized this in 1937, stating:

> We fully recognize that regulations of this kind cannot provide a complete answer to the problem of driver fatigue and its effect upon safety of operation. We have no control over the manner in which a driver may spend his time off duty, although some of his spare-time activities may tire him quite as much as any work would do. We can only emphasize, by this comment, the responsibility which is the driver's own to assure himself of adequate rest and sleep, in the time available for this purpose, to ensure the safety of his driving, and likewise the employer's responsibility to see that his drivers report for work in fit condition.

Although drivers have a responsibility to obtain adequate rest and sleep, they must first recognize that they need sleep. Many of the truckdrivers in the Safety Board's accident sample who were involved in fatigue-related accidents did not recognize that they were in need of sleep and believed that they were rested when they were not. Drivers in both fatigue-related and nonfatigue-related accidents rated themselves as being okay to fully alert before the accident. Further, about 80 percent of the drivers involved in fatigue-related accidents rated the quality of their last sleep before the accident as good or excellent. Drivers in fatigue-related accidents received about 1.4 hours less sleep than they reported needing to feel rested. Research has indicated that people "...have a limited ability to predict the onset of sleep...[and that]...subjects certainly do fall asleep at times when they think sleep is highly unlikely."[69]

"Inadequate sleep, even as little as 1 or 2 hours less than usual sleep, can greatly exaggerate the tendency for error during the time zones of vulnerability (1 to about 8 a.m. and 2 to roughly 6 p.m.)."[70] The majority of the accidents in this sample occurred between 2 and 8 a.m. (53 percent), and an even higher percentage of the accidents that were found to be fatigue-related occurred during these same hours (75 percent). Driving at night, as many truckdrivers must do, is complicated by the effects of circadian rhythms (see appendix A for a discussion of the circadian clock). Thus, a sleep deprived person driving at night is in the highest risk situation—a risk that many drivers may not be aware of or recognize.

Modifying the regulations to increase the off-duty period will not, by itself, eliminate the problem of truckdriver fatigue. Educating transportation employees

---

[69] Itoi, A.; Cilveti, R.; Voth, M.; and others. 1993. Can drivers avoid falling asleep at the wheel? Relationship between awareness of sleepiness and ability to predict sleep onset. Washington, DC: AAA Foundation for Traffic Safety (p. 25). 33 p.

[70] Mitler, M.; Carskadon, M.A.; Czeisler, C.A.; and others. 1988. Catastrophes, sleep and public policy: consensus report. Sleep. 11(1): 100-109.

about the effects of fatigue, in the Safety Board's view, is a vitally important component of overall efforts to combat fatigue in transportation. In January 1994, the Safety Board published a study of 37 major aviation accidents from the period 1978 through 1990, in which human performance issues were cited in the probable cause determinations.[71] Many human performance background variables were compared to the types of errors observed in the accident sequences in an effort to identify factors that might be useful in accident prevention. Several fatigue-related variables were examined, such as time since awakening, time of day, time zone crossings, and changing work schedules. It was found that the time since awakening for each pilot related to significant differences in performance, in terms of the number and types of errors made by pilots. As a result of the study, the Safety Board recommended that the Federal Aviation Administration:

> Require U.S. air carriers operating under 14 CFR Part 121 to include, as part of pilot training, a program to educate pilots about the detrimental effects of fatigue, and strategies for avoiding fatigue and countering its effects. (A-94-5)[72]

Research has shown that individuals tend to subjectively rate themselves as more alert than they may be physiologically. Several factors can affect an individual's subjective report of sleepiness and mask or conceal an individual's level of physiological sleepiness; these factors include caffeine, physical activity, and external stimulation (see appendix A). The Safety Board has addressed providing education to operating crewmembers about the effects of fatigue in other modes of transportation as well. As a result of the Board's investigation of the head-on collision of two trains at Thompsontown, Pennsylvania, mentioned in the introduction to this study, the Board recommended that the Association of American Railroads (AAR) "encourage its member railroads to provide education and counseling to employees on proper health regimens and avoidance of sleep deprivation."[73] The Board also recommended that the AAR, in cooperation with member carriers and the operating unions, develop a policy that would allow the carrier to prevent an employee from accepting assignments and would allow an employee to report off duty when he or she is impaired by lack of sleep."[74] In response to this recommendation,

---

[71] National Transportation Safety Board. 1994. A review of flightcrew-involved major accidents of U.S. air carriers, 1978 through 1990. Safety Study NTSB/SS-94/01. Washington, DC.

[72] Based on the Federal Aviation Administration's response of April 26, 1994, Safety Recommendation A-94-5 was classified "Open—Acceptable Response."

[73] This safety recommendation, R-89-32, was classified "Closed—Acceptable Action" in April 1990, as a result of the AAR's encouragement to its member railroads to provide the education recommended.

[74] National Transportation Safety Board. 1991. Atchison, Topeka, and Santa Fe Railway Company (ATSF) freight trains ATSF 818 and ATSF 891 on the ATSF Railway, Corona, California, November 7, 1990. Railroad Accident Report NTSB/RAR-91/03. The recommendation issued to the Association

(continued...)

the Railroad Work/Rest Review Task Force, made up of representatives of the AAR, the Brotherhood of Locomotive Engineers, and the United Transportation Union, has initiated a study to examine the effects of work schedules on operating crew performance; preliminary efforts have analyzed engineers' schedules with accident/incidents. According to the Task Force, preliminary results suggest that improved communication with crews about the effects of fatigue would appear to be an effective strategy at this time.

As a result of its 1990 study on fatal-to-the-truckdriver accidents, the Safety Board made recommendations to several agencies and organizations that addressed the dissemination of information regarding the effects of alcohol, drugs, and fatigue. The Board believes that these recommendations continue to have merit and will follow up with the recipients of these recommendations regarding implementation. However, the accident data in this study clearly indicate that truckdrivers need specifically a better understanding of sleep loss and of the need to receive adequate sleep.

The Board recognizes that there is a considerable amount of research underway that could eventually be used to develop or modify programs designed to educate operators of heavy trucks and other industry personnel, in particular management, about the importance of sleep loss and other factors in fatigue-related accidents. However, the Board believes that this study and other research have provided important information that could be provided now to truckdrivers and management about factors leading to fatigue and possible strategies to combat fatigue. In addition to studies discussed above, the NASA Ames Fatigue Countermeasures Program stands out as demonstrating some especially effective countermeasures. This program, which has been underway since 1980, has addressed strategic napping as a preventive strategy and an operational countermeasure to combat sleep loss, circadian disruption, and fatigue that occur as a result of multiple time zone changes, and extended, irregular duty schedules in flight operations.[75] The researchers found that there is scientific evidence showing that as a preventive strategy, napping before fatigue develops is quite effective in an operational setting. A single nap of about 45 minutes in duration prior to a night without sleep can prevent significant loss of performance capability and fatigue throughout the night. The Safety Board agrees that the use of naps as a means to prevent fatigue prior to its onset is a worthwhile countermeasure. The Board cautions, however, that these naps should be a supplement to, not a replacement for, one continuous 8-hour sleep period.

Therefore, the Safety Board believes that the Federal Highway Administration, the Professional Truck Driver Institute of America, the American Trucking Associations, Inc., the Commercial Vehicle Safety Alliance, and the National Private

---

[74] (...continued)
of American Railroads in conjunction with this report, R-95-45, is currently classified "Open—Acceptable Response."

[75] Rosekind and others (1993).

Truck Council, in consultation with the U.S. Department of Transportation Human Factors Coordinating Committee, should cooperatively develop and disseminate a training and education module that includes information about the need for an adequate amount of quality sleep, strategies for avoiding sleep loss such as strategic napping, consideration of the behavioral and physiological consequences of sleepiness, and an awareness that sleep can occur suddenly and without warning to all drivers regardless of their age or experience. Because of the strides that have been made in this area in the other transportation modes, particularly in aviation by NASA Ames, the Board urges the FHWA to consult the other modal administrations before developing this training and education module. The development and dissemination of this training module would satisfy the highway portion of the intermodal Safety Recommendation I-89-02.

Another measure that was relatively highly correlated with fatigue was split sleep patterns. Split sleep patterns also ranked fifth in importance in discriminating between long-haul and short-haul operations. The HOS regulations contain an exemption that allows drivers using Department of Transportation-approved sleeper berth equipment to accumulate the required 8 consecutive hours off duty resting in a sleeper berth in two separate periods totaling 8 hours (neither period to be less than 2 hours).

The findings of this study show that truckdrivers with split sleep patterns were obtaining about 8 hours of sleep in a 24-hour time period; however, they obtained it in segments, on average of 4 hours at a time. Research, not available at the time the regulations were drafted by the Interstate Commerce Commission, has shown that sleep accumulated in short time blocks is less refreshing than sleep accumulated in one long time period.[76] Other research indicates that "...the more sleep is disturbed or reduced, for whatever reason, the more likely an individual will inadvertently slip into sleep."[77] A review of police accident reports has also demonstrated that decrements in performance occur earlier for drivers using sleeper berths (or drivers with split sleep patterns) than for other drivers. The same research determined that split-shift, sleeper berth use (that is, driving without an 8-hour consecutive rest period) increased the risk of fatality more than two-fold. Sleep duration has been found to be as important to the recovery of performance abilities as is the quality of sleep experience.[78] Of the drivers in the Safety Board's sample for whom information on duty hours was available, 19 of 26 drivers with split sleep patterns (73 percent) had slept in a sleeper berth.

---

[76] Dinges, D.F. 1989. The nature of sleepiness: causes, contexts, and consequences. In: Stunkard, A.J.; Baum, A. Perspectives in behavioral medicine: eating, sleeping, and sex. Hillsdale, NJ: Lawrence Erlbaum Associates: 147-179. Chapter 9 (p. 147).

[77] (a) Mitler and others (1988, p. 107). (b) Rosekind and others (1994).

[78] Hertz, R.P. 1988. Tractor-trailer driver fatality: the role of nonconsecutive rest in a sleeper berth. Accident Analysis and Prevention. 20(6): 431-439.

In drafting its original regulations, the ICC noted the lack of scientific evidence about the nature of fatigue. The ICC was clearly frustrated at being unable to base its regulations on an empirical understanding of driver fatigue. Given what is now known about the inferior nature of split sleep patterns, it is unclear that the ICC would have permitted sleeper berth drivers to divide their required 8-hour off-duty period into two segments. Although the Safety Board encourages the use of sleeper berths for strategic napping and recognizes that sleeper berths may allow for continuous sleep, truckdrivers should not be encouraged or permitted to split their sleep. The current hours-of-service regulations do not permit drivers who sleep at a residence or in a motel to split their sleep periods. This exemption applies only to drivers who use sleeper berths. The Safety Board understands that in 1937, when these regulations were written, economic considerations required that freight move continuously—to keep produce and dairy products from spoiling, for example. However, the advent of refrigerated trucks eliminated concerns about food spoilage. The Board is also aware that the trucking industry wanted the flexibility provided by having drivers rest in their sleeper berths while waiting for other tasks to be completed (such as loading of tanks with crude oil). This would enable drivers to begin driving as soon as the tasks were completed and to drive for at least the time that they spent resting in their berths.

Although the Board is aware of the importance of just-in-time deliveries to the economic well-being of the manufacturing industry, the Board does not believe that this flexibility should be permitted at the expense of safety. The Safety Board is not aware of any physiological or laboratory research regarding the effect of split sleep patterns on performance; however, the Board's analysis has shown that the length of the most recent sleep period is the most important factor in determining fatigue and that the continuous nature of that sleep also is very important. Consequently, the Safety Board believes that the Federal Highway Administration should complete rulemaking within 2 years to eliminate 49 CFR 395.1 paragraph (h), which allows drivers with sleeper berth equipment to cumulate the 8 hours of off-duty time in two separate periods.

The Safety Board has previously expressed its view that carriers and shippers share responsibility in helping to eliminate fatigue involvement in truck accidents. As a result of its 1990 study on fatal-to-the-driver truck accidents, the Safety Board issued Safety Recommendation H-90-32 to the FHWA, which asked the FHWA to:

> Amend CFR part 392 and 395 to prohibit employers, shippers, receivers, brokers, or drivers from accepting and scheduling a shipment which would require that the driver exceed the hours-of-service regulations in order to meet the delivery deadline (similar to current regulations regarding schedules which would require the driver to exceed the speed limit (49 CFR Section 392.6)). In conjunction with the Interstate Commerce Commission, provide for operating certificate and financial penalties appropriate to the offense.

The FHWA has recently indicated to the Safety Board that a research project for FY95 will investigate the role of shippers and other parties in commercial transportation. The Safety Board firmly believes that carriers and shippers share responsibility with drivers regarding adherence to the HOS regulations and the prevention of driver fatigue. The Board is aware that some carriers have implemented satellite tracking as a management tool to track shipments and facilitate communications with the drivers. This existing technology could also serve to monitor on-duty times of the drivers to help drivers plan and obtain adequate rest during their off-duty hours. The Safety Board encourages the FHWA to address the issue of the role of shippers and carriers with respect to adherence to the HOS regulations in its 1995 project. However, the Safety Board recognizes that the role of the Interstate Commerce Commission, which is addressed in the recommendation, has changed. Consequently, Safety Recommendation H-90-32 is being classified "Closed—Acceptable Action/Superseded," and a new recommendation, albeit similar, is being issued in conjunction with this study.

The results of this study also raise questions about the influence of pay policies on truckdriver fatigue. About 65 percent of the drivers (28 of 43) who were paid by the mile had a fatigue-related accident compared to 46 percent of the drivers paid by a percent of load revenue (13 of 28) and 27 percent of drivers paid by the hour (3 of 11). Pay practices in this sample appeared to be associated with the type of trucking operation. About 77 percent of the drivers paid by the mile (33 of 43) were long-haul drivers. In contrast, none of the 11 drivers paid by the hour and only 25 percent of the drivers paid by a percent of load revenue (7 of 28) were long-haul drivers. Further, of the 27 drivers who exceeded the hours-of-service limits, 57 percent (15 drivers) were paid by the mile and 30 percent (8 drivers) were paid by a percent of load revenue. These results raise questions about a possible link between the method of compensation and fatigue-related accidents. It is the Safety Board's understanding that the FHWA has not previously examined any effect between pay policies and truck accidents. The Board believes, therefore, that the FHWA should examine the methods in which truckdrivers are compensated for their trips and determine if there is an effect on hours-of-service violations, accidents, or fatigue.

Another countermeasure to reduce the number of fatigue-related accidents is the use of on-board electronic recording devices in trucks. These monitors have been proposed by the Safety Board as a means to identify drivers who exceed the hours-of-service limits. As a result of its 1990 study on fatal-to-the-driver truck crashes, the Safety Board recommended that the FHWA "require automated/tamper-proof on-board recording devices such as tachographs or computerized logs to identify commercial truck drivers who exceed hours-of-service regulations" (Safety Recommendation H-90-28).[79] The Board reasoned that if law enforcement personnel could routinely examine data from on-board recorders instead of written logbooks, these devices could, in theory, reduce HOS violations by discouraging carriers from setting unrealistic delivery times as well as discouraging drivers from driving too long

---

[79] National Transportation Safety Board. Safety Study NTSB/SS-90/01.

or exceeding the speed limit. The FHWA has not agreed with the intent of this recommendation stating that the recommendation was tantamount to a design standard and not in keeping with agency policy to issue performance standards whenever possible and that the devices have not yet been proven to be of such value as to warrant mandatory use. In its response to the FHWA, dated August 4, 1994, the Board reiterated its position that because the recommendation calls only for a tamper-proof means of recording data and does not specify the means, the Board is asking only for a performance standard and not a design standard. The Board further noted that new trucks are highly computerized with automated fuel management and maintenance systems built into the vehicles and that some carriers are now requiring on-board recording devices as part of driver speed control and fuel incentive pay systems. The Board continues to believe in the merits of Safety Recommendation H-90-28, which is currently classified "Open--Unacceptable Response," and is reiterating the recommendation as a result of this study.

Conclusions

1. The most critical factors in predicting fatigue-related accidents in the Board's sample are the duration of the most recent sleep period, the amount of sleep in the past 24 hours, and split sleep patterns.

2. Whereas sleep measures were the critical factors in discriminating between a fatigue-related and nonfatigue-related accident, schedule irregularity was the major factor in discriminating between a long-haul and short-haul operation.

3. The truckdrivers in fatigue-related accidents in this sample obtained an average of 5.5 hours sleep in the last sleep period prior to the accident. This was 2.5 hours less than the drivers involved in nonfatigue-related accidents (8.0 hours).

4. The truckdrivers involved in fatigue-related accidents obtained 6.9 hours sleep in the 24 hours prior to the accident (the amount they reported usually needing to feel rested). This was 2.4 hours less sleep than the drivers involved in nonfatigue-related accidents (9.3 hours).

5. The hours-of-service regulations currently do not provide the opportunity to obtain an adequate amount of sleep (at least 8 continuous hours) because they do not consider time needed for travel, eating, personal hygiene, recreation, or inability to fall asleep immediately at the beginning of the 8-hour off-duty period.

6. Many of the truckdrivers in the accident sample who were involved in fatigue-related accidents did not recognize that they were in need of sleep and believed that they were rested when they were not. About 80 percent of the drivers involved in fatigue-related accidents rated the quality of their last sleep before the accident as good or excellent.

7. The data from this study indicate that driving at night with a sleep deficit is far more critical in terms of predicting fatigue-related accidents than simply nighttime driving.

8. Truckdrivers with split sleep patterns obtained about 8 hours sleep in a 24-hour time period; however, they obtained it in small segments, on average of 4 hours at a time. The data and research indicate that sleep accumulated in short time blocks impedes the recovery of performance abilities.

9. The use of the sleeper berth exemption [now found in 49 CFR 395.1(h)] promotes split sleeping that can result in performance decrements earlier than for drivers who obtain sleep in longer continuous periods.

10. About 67 percent of the drivers with schedule irregularities were involved in fatigue-related accidents (48 of 73), and about 38 percent of drivers with regular schedules had fatigue-related accidents (13 of 34). Seventeen of the 107 drivers had inverted their duty/sleep periods on the accident trip; that is, the accident occurred at a time when on the previous day the driver had been sleeping. All but one of these drivers (94 percent) had a fatigue-related accident. Irregular and inverted schedules can result in longer hours awake than normal and can prevent drivers from obtaining adequate sleep without careful planning.

11. Twenty-seven of the 107 drivers exceeded the hours-of-service limits at least once in the 96 hours preceding the accident. Of those drivers who exceeded the limits, about 82 percent (22 of 27) had a fatigue-related accident. The obvious implication for drivers who exceed the hours-of-service limits is the fewer number of hours available to obtain adequate sleep.

12. Providing education to transportation employees about the factors affecting fatigue is a vitally important component of overall efforts to combat fatigue in transportation.

13. The results of this study suggest a possible link between the method of driver compensation and fatigue-related accidents—an issue that has not been previously addressed in detail.

Recommendations

As a result of this safety study, the National Transportation Safety Board made the following safety recommendations:

to the Federal Highway Administration—

Complete rulemaking within 2 years to revise 49 CFR 395.1 to require sufficient rest provisions to enable drivers to obtain at least 8 continuous hours of sleep after driving for 10 hours or being on duty for 15 hours. (Class II, Priority Action) (H-95-1)

Complete rulemaking within 2 years to eliminate 49 CFR 395.1 paragraph (h), which allows drivers with sleeper berth equipment to cumulate the 8 hours of off-duty time in two separate periods. (Class II, Priority Action) (H-95-2)

Examine truckdriver pay compensation to determine if there is any effect on hours-of-service violations, accidents, or fatigue. (Class II, Priority Action) (H-95-3)

Complete rulemaking within 2 years to amend 49 CFR Part 392 and 395 to prohibit employers, shippers, receivers, brokers, or drivers from accepting and scheduling a shipment which would require that the driver exceed the hours-of-service regulations in order to meet the delivery deadline (similiar to current regulations regarding schedules which would require the driver to exceed the speed limit [49 CFR 392.61]). (Class II, Priority Action) (H-95-4) (Supersedes H-90-32) *to the Federal Highway Administration, the Professional Truck Driver Institute of America, the American Trucking Associations, Inc., the Commercial Vehicle Safety Alliance, and the National Private Truck Council—*

Develop and disseminate, in consultation with the U.S. Department of Transportation Human Factors Coordinating Committee, a training and education module to inform truckdrivers of the hazards of driving while fatigued. It should include information about the need for an adequate amount of quality sleep, strategies for avoiding sleep loss such as strategic napping, consideration of the behavioral and physiological consequences of sleepiness, and an awareness that sleep can occur suddenly and without warning to all drivers regardless of their age or experience. (Class II, Priority Action) (H-95-5)

to the American Trucking Associations, Inc., the National Private Truck Council, and the National Industrial Transportation League, the Independent Truck Owner Operators, the Owner-Operator Independent Driver's Association, and the International Brotherhood of Teamsters—

Urge your members to incorporate into their scheduling practices and procedures the results of the latest research on fatigue and sleep issues, particularly that an 8-hour continuous sleep need is the norm. (Class II, Priority Action) (H-95-6)

As a result of this study, the National Transportation Safety Board also reiterated the following safety recommendation to the Federal Highway Administration:

Require automated/tamper-proof on-board recording devices such as tachographs or computerized logs to identify commercial truck drivers who exceed hours-of-service regulations. (H-90-28)

By the National Transportation Safety Board

James E. Hall
Chairman

John A. Hammerschmidt
Member

Robert T. Francis II
Member

Adopted: January 18, 1995

Appendix A

Discussion of Basic Human Sleep and Circadian Physiology

This appendix contains an excerpt of an article published by the Safety Board in its report of the aircraft accident in Guantanamo Bay, Cuba, August 18, 1993 (Aviation Accident Report NTSB/AAR-94/04).

Analysis of Crew Fatigue Factors in AIA Guantanamo Bay Aviation Accident

Mark R. Rosekind, Kevin B. Gregory,[1] Donna L. Miller,[1]
Elizabeth L. Co,[2] and J. Victor Lebacqz

Flight Human Factors Branch
NASA Ames Research Center

Introduction

Flight operations can engender sleep loss and circadian disruption that can affect flight crew performance, vigilance, and mood. Scientific information on sleep and circadian rhythms acquired over the past 40 years has clearly established human requirements for sleep and the detrimental effects of sleep loss and circadian disruption. The application of this scientific information to the 24-hour requirements of flight operations has been underway for over 12 years. A variety of sources clearly indicates that fatigue, as a result of sleep loss and circadian disruption, is an aviation safety issue that warrants attention.

The NASA Aviation Safety Reporting System (ASRS) is a confidential reporting system for flight crews and others to report difficulties and incidents in the National Airspace System. Approximately 21% of the incidents reported to ASRS are fatigue-related (ref. 1). Since its inception, ASRS has accumulated over 261,000 incident reports with about 52,000 of these reporting a fatigue-related occurrence. Since 1980, the NASA Ames Fatigue Countermeasures Program has examined the extent and effects of fatigue. sleep loss, and circadian disruption in a variety of flight environments (refs. 2, 3). This Program has collected anecdotal, subjective, physiological, and performance data documenting fatigue issues in flight operations (e.g., see refs. 4-8). The FAA has identified fatigue research as an important aviation safety issue in its National Plan for Aviation Human Factors. The National Transportation Safety Board (NTSB) has, on several occasions, called for specific actions regarding fatigue, including coordination of federal research activities, review and revision of hours of service regulations, and the dissemination of educational materials. Scientific data has clearly indicated that fatigue can be a factor in 24-hour operational environments, including aviation. This has been recognized at the Federal level by the FAA, the NTSB, other Federal agencies (e.g., Office of Technology Assessment, Federal Highway Administration), and ongoing NASA activities.

---

[1] Sterling Software, Inc.

[2] San Jose State University Foundation.

Basic Human Physiology: Sleep and Circadian Rhythms

The era of modern sleep research began in the mid-1950's with the discovery of two distinct states of sleep (ref. 9). Over the past 40 years, there has been extensive scientific research on sleep, sleepiness, circadian rhythms, sleep disorders, dreams, and the effects of these factors on waking alertness and human performance (e.g., see refs. 10, 11). Some of this basic information regarding human sleep, sleepiness, and circadian rhythms is presented as a foundation for examining the specifics of the AIA aviation accident at Guantanamo Bay.

1. Sleep is a vital human physiological function.

Historically, sleep has been viewed as a state when the human organism is turned off. Scientific findings have clearly established that sleep is a complex, active physiological state that is vital to human survival. Like human requirements for food and water, sleep is a vital physiological need. When an individual is deprived of food and water, the brain provides specific signals—hunger and thirst—to drive the individual to meet these basic physiological needs. Similarly, when deprived of sleep, the physiological response is sleepiness. Sleepiness is the brain's signal to prompt an individual to obtain sleep. Sleepiness is a signal that a specific physiological requirement has not been met. Eventually, when deprived of sleep (acutely or chronically), the human brain can spontaneously, in an uncontrolled fashion, shift from wakefulness to sleep in order to meet its physiological need for sleep. The sleepier the person, the more rapid and frequent are these intrusions of sleep into wakefulness. These spontaneous sleep episodes can be very short (i.e., microsleeps lasting only seconds) or extended (i.e., lasting minutes). At the onset of sleep, an individual disengages perceptually from the external environment, essentially ceasing to integrate outside information. In a sleepy person, performance can begin to slow even before actual sleep intrusions into waking. A microsleep can be associated with a significant performance lapse when an individual does not receive or respond to external information. With sleep loss, these uncontrolled sleep episodes can occur while standing, operating machinery, and even in situations that would put an individual at risk, such as driving a car (refs. 12-14).

How much sleep does an individual need? Basically, an individual requires the amount of sleep necessary to achieve full alertness and their highest level of functioning during their waking hours. There is a range of individual sleep needs and, though most adults will require about 8 hours of sleep, some people need 6 hours while others require 10 hours to feel wide awake and function at their peak level during wakefulness.

2. Sleepiness affects waking performance, vigilance, and mood.

Sleep loss creates sleepiness and often this sleepiness is dismissed as a minimal nuisance or easily overcome. However, sleepiness can potentially degrade most aspects of human capability. Controlled laboratory experiments have demonstrated decrements in most components of human performance, vigilance, and mood as a result of sleep loss. Sleepiness can be associated with decrements in decision-making, vigilance, reaction time, memory, psychomotor coordination, and information processing (e.g., fixation on certain material to the neglect of other information). Research has demonstrated that with increasing sleepiness, individuals demonstrate poorer performance despite increased effort, and may report indifference regarding the outcome of their performance. Individuals report fewer positive emotions, more negative emotions, and an overall worsened mood with sleep loss and sleepiness (for scientific reviews of this area, see ref. 15-18).

Generally, sleepiness can degrade most aspects of human waking performance, vigilance, and mood. In the most severe instances, an individual may experience an uncontrolled sleep episode and obviously be unable to perform. However, in many other situations, while the individual may not actually fall asleep, the level of sleepiness can still significantly degrade human performance. For example, the individual may react slowly to information, may incorrectly process the importance of the information, may find decision making difficult, may make poor decisions, may have to check and recheck information or activities because of memory difficulties. This performance degradation can be a direct result of sleep loss and the associated sleepiness and can play an insidious role in the occurrence of an operational incident or accident (ref. 19-21).

3. Sleep loss accumulates into a sleep debt.

An individual who requires 8 hours of sleep and obtains only 6 hours is essentially sleep deprived by 2 hours. If the individual sleeps only 6 hours over 4 nights, then the 2 hours of sleep loss per night would accumulate into an 8-hour sleep debt. Estimates suggest that in the United States today, most adults obtain 1 to 1.5 hours less sleep per night than they actually need (ref. 22). During a regular work week this would translate into the accumulation of a 5 to 7.5-hour sleep debt going into the weekend; hence, the common phenomenon of sleeping late on weekends to compensate for the sleep debt accumulated during the week. Generally, recuperation from a sleep debt involves obtaining deeper sleep over 2 to 3 nights. Obtaining deeper sleep appears to be a physiological priority over a significant increase in the total hours of sleep (i.e., sleeping 7.5 hours longer on the weekend to "make-up" for the sleep debt accumulated during the week).

4. Physiological vs. Subjective Sleepiness

Sleepiness can be differentiated into two distinct components: physiological and subjective. Physiological sleepiness is the result of sleep loss: lose sleep, get sleepy. An accumulated sleep debt will be accompanied by physiological sleepiness that will drive an individual to sleep in order to meet the individual's physiological need. Subjective sleepiness is an individual's introspective self-report regarding the individual's level of sleepiness (refs. 12, 23). An individual's subjective report of sleepiness can be affected by many factors. For example, caffeine, physical activity, and a particularly stimulating environment (e.g., an interesting conversation) can all affect an individual's subjective rating of sleepiness. However, an individual will typically report being more alert because of these factors. These factors can affect the subjective report of sleepiness and mask or conceal an individual's level of physiological sleepiness. Therefore, the tendency will be for individuals to subjectively rate themselves as more alert than they may be physiologically. This discrepancy between subjective sleepiness and physiological sleepiness can be operationally significant. An individual might report a low level of sleepiness (i.e., that they are alert) but be carrying an accumulated sleep debt with a high level of physiological sleepiness. This individual, in an environment stripped of factors that conceal the underlying physiological sleepiness, would be susceptible to the occurrence of spontaneous, uncontrolled sleep and the performance decrements associated with sleep loss (refs. 24-26).

5. The Circadian Clock.

Humans, like other living organisms, have a circadian (circa=around, dia=a day) clock in the brain that regulates physiological and behavioral functions on a 24-hour basis. In a 24-hour period this clock will regulate our sleep/wake pattern, body temperature, hormones, performance, mood, digestion, and many other human functions. For example, on a regular 24-hour schedule we are programmed for periods of wakefulness and sleep, high and low body temperature, high and low digestive activity, increased and decreased performance capability, etc. An individual's circadian clock might be programmed to sleep at midnight, awaken at 8 AM, and maintain wakefulness during the day (with an afternoon sleepiness period), and then the 24-hour pattern repeats itself. The circadian rhythm of body temperature is programmed for the lowest temperature between 3 and 5 AM on a daily basis (ref. 27).

When the circadian clock is moved to a new work/rest (or sleep/wake) schedule or put in a new environmental time zone, it does not adjust immediately. This is the basis for the circadian disruption associated with jet lag. Once the circadian clock is moved to a new schedule or time zone, it can begin to adjust and may take from several days up to several weeks to physiologically adapt to the new environmental time. Also, the body's internal physiological rhythms do not all adjust at the same rate and therefore, may be out of synch with each other for an extended period of time. Again, it can take from days to weeks for all of the internal rhythms to come together in a synchronous 24-hour rhythm on the new schedule or time zone. There are some specific factors that can affect the circadian clock's adaptation. Day/night reversal can confuse the clock so that the cues that help it adjust and maintain its usual physiological pattern are disrupted. Moving from a day to night schedule and back to days can keep the clock in a continuous state of readjustment, depending on the time between schedule changes. For example, severe effects would accompany a 12-hour day to night to day schedule alteration. Another factor is crossing multiple time zones. While there is some flexibility for adjustment, putting the circadian clock in a time zone three or more hours off home time will require a reasonable amount of physiological adaptation. Another factor can be the direction the clock is moved. Shortening the period (e.g., moving to a 21-hour cycle or day) is generally more difficult to achieve than is lengthening the period (e.g., moving to 25 or longer hours), which is the natural rhythm of the circadian clock. Therefore, it can be more difficult to cross time zones in an eastward direction compared to westward movement. It can also be more difficult to move a work/rest schedule backwards over the 24-hour day compared to moving it forward (e.g., forward from day to swing to night shift). All of the associated difficulties of moving the clock, such as poor sleep, sleepiness, effects on performance, etc., will be affected until the circadian clock physiologically adapts to the new schedule or time zone (refs. 28, 29).

Scientific studies have revealed that there are two periods of maximal sleepiness during a usual 24-hour day. One occurs at night roughly between 3 and 5 AM, and the other in midday roughly between 3 and 5 PM. However, performance and alertness can be affected throughout a 12 AM to 8 AM window. Individuals on a regular day/night schedule will typically sleep through the 3-5 AM window of sleepiness. The afternoon sleepiness period can be masked by factors described previously, or present a window when individuals are particularly vulnerable to the effects of sleepiness. This also means that individuals working through the night are maintaining wakefulness from 3-5 AM when their circadian clock is programmed for sleep. Conversely, individuals sleeping during the day are attempting to sleep when the circadian clock is programmed for wakefulness. However, individuals searching for specific windows when they are physiologically prepared to sleep, either for an extended sleep period or a strategic nap, can use these periods to their advantage (ref. 12).

[The remainder of the article contains a detailed discussion of the crew fatigue factors in the Guantanamo Bay accident. See NTSB/AAR-94/04.]

References

1. Lyman, E.G., & Orlady, H.W. (1980). *Fatigue and Associated Performance Decrements in Air Transport Operations.* NASA Contract NAS2-10060. Mountain View, CA: Battelle Memorial Laboratories, Aviation Safety Reporting System.

2. Rosekind, M.R., Gander, P.H., Miller, D.L., Gregory, K.B., McNally, K.L., Smith, R.M., & Lebacqz, J.V. (1993). NASA Ames Fatigue Countermeasures Program. *FAA Aviation Safety Journal,* 3(1), 20-25.

3. Rosekind, M.R., Gander, P.H., Miller, D.L., Gregory, K.B., Smith, R.M., Weldon, K.J., Co, E.L., McNally, K.L., and Lebacqz, J.V. (in press). Fatigue in Operational Settings: Examples from the Aviation Environment. *Human Factors.*

4. Gander, P.H., Graeber, R.C., Foushee, H.C., Lauber, J.K., & Connell, L.J. (in press). *Crew Factors in Flight Operations II: Psychophysiological Responses to Short-Haul Air Transport Operations.* NASA Technical Memorandum. Moffett Field, CA: NASA Ames Research Center.

5. Gander, P.H., Graeber, R.C., Connell, L.J., & Gregory, K.B. (1991). *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews.* NASA Technical Memorandum 103852. Moffett Field, CA: NASA Ames Research Center.

6. Gander, P.H., Barnes, R.M., Gregory, K.B., Connell, L.J., Miller, D.L., & Graeber, R.C. (in press). *Crew Factors in Flight Operations VI: Psychophysiological Responses to Helicopter Operations.* NASA Technical Memorandum. Moffett Field, CA: NASA Ames Research Center.

7. Gander, P.H., et al. (in preparation). *Crew Factors in Flight Operations VII: Psychophysiological Responses to Overnight Cargo Operations.* NASA Technical Memorandum. Moffett Field, CA: NASA Ames Research Center.

8. Rosekind, M.R., Graeber, R.C., Dinges, D.F., Connell, L.J., Rountree, M.S., & Gillen, K. (in press). *Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations.* NASA Technical Memorandum. Moffett Field, CA: NASA Ames Research Center.

9. Dement, W.C. (1994). History of Sleep Physiology and Medicine. In M.H. Kryger, T. Roth, & W.C. Dement (Eds.), *Principles and Practice of Sleep Medicine.* Philadelphia, PA: Saunders.

10. Kryger, M.H., Roth T., & Dement, W.C. (Eds.). (1994). *Principles and Practice of Sleep Medicine.* Philadelphia, PA: Saunders.

11. Carskadon, M.A. (Ed.). (1993). *Encyclopedia of Sleep and Dreaming.* New York, NY: Macmillan.

12. Roth T., Roehrs, T.A., Carskadon, M.A., Dement, W.C. (1994). Daytime Sleepiness and Alertness. In M.H. Kryger, T. Roth, & W.C. Dement (Eds.), *Principles and Practice of Sleep Medicine.* Philadelphia, PA: Saunders.

13. Mitler, M.M., Carskadon, M.A., Czeisler, C.A., et al. (1988). Catastrophes, Sleep, and Public Policy: Consensus Report. *Sleep, 11,* 100-109.

14. Akerstedt, T. (1988). Sleepiness as a Consequence of Shift Work. *Sleep,* 11(1), 17-34.

15. Broughton, R.J. & Ogilvie, R.D. (Eds.). (1992). *Sleep, Arousal, and Performance.* Boston, MA: Birkhäuser-Boston, Inc.

16. Dinges, D.F. (1990). Are You Awake? Cognitive Performance and Reverie During the Hypnopompic State. In R. Bootzin, J. Kihlstrom, & D. Schacter (Eds.), *Sleep and Cognition.* Washington, D.C.: American Psychological Association.

17. Dinges, D.F. & Kribbs, N.B. (1991). Performing while Sleepy: Effects of Experimentally-Induced Sleepiness. In T. Monk (Ed.), *Sleep, Sleepiness and Performance.* Chichester, UK: John Wiley and Sons, Ltd.

18. Horne, J.A. (1978). A Review of the Biological Effects of Total Sleep Deprivation in Man. *Biological Psychology,* 7, 55-102.

19. Dinges, D.F. (1992). Probing the Limits of Functional Capability: The Effects of Sleep Loss on Short-Duration Tasks. In R.J. Broughton & R. Ogilvie (Eds.), *Sleep, Arousal and Performance: Problems and Promises.* Boston: Birkhäuser-Boston, Inc.

20. Dinges, D.F., & Broughton, R.J. (Eds.). (1989). *Sleep and Alertness: Chronobiological, Behavioral, and Medical Aspects of Napping.* New York: Raven Press.

21. Graeber, R.C. (1988). Aircrew Fatigue and Circadian Rhythmicity. In E.L. Weiner & D.C. Nagel (Eds.), *Human Factors in Aviation.* New York: Academic Press.

22. *Wake Up America: A National Sleep Alert.* (1993). Report of the National Commission on Sleep Disorders Research.

23. Sasaki, M., Kurosaki, Y., Mori, A., & Endo, S. (1986). Patterns of Sleep-Wakefulness Before and After Transmeridian Flight in Commercial Airline Pilots. *Aviation, Space, and Environmental Medicine,* 57(12), B29-B42.

24. Torsvall, L. & Akerstedt, T. (1978). Sleepiness on the Job: Continuously Measured EEG Changes in Train Drivers. *Electroencephalography and Clinical Neurophysiology,* 66, 502-511.

25. Akerstedt, T., Torsvall, L., & Gillberg, M. (1987). Sleepiness in Shift-Work: A Review with Emphasis on Continuous Monitoring of EEG and EOG. *Chronobiology International, 4,* 129-140.

26. Akerstedt, T. (1992). Work Hours and Continuous Monitoring of Sleepiness. In R.J. Broughton & R.D. Ogilvie (Eds.). *Sleep, Arousal, and Performance.* Boston, MA: Birkhäuser-Boston, Inc.

27. Kryger, M.H., Roth T., & Carskadon, M.A. (1994). Circadian Rhythms in Humans: An Overview. In M.H. Kryger, T. Roth, & W.C. Dement (Eds.), *Principles and Practice of Sleep Medicine.* Philadelphia, PA: Saunders.

28. Monk, T. (1994). Shift Work. In M.H. Kryger, T. Roth, & W.C. Dement (Eds.), *Principles and Practice of Sleep Medicine.* Philadelphia, PA: Saunders.

29. Graeber, R.C. (1994). Jet Lag and Sleep Disruption. In M.H. Kryger, T. Roth, & W.C. Dement (Eds.), *Principles and Practice of Sleep Medicine.* Philadelphia, PA: Saunders.

Appendix B

Information on Vehicles in Study Sample

Table B.1—Information about the vehicles involved in the 107 accidents in the accident sample

Item	Number involved in a fatigue-related accident (n = 62)	Number involved in a nonfatigue-related accident (n = 45)	Total (n = 107)
Vehicle make:			
Freightliner	21	10	31
Peterbilt	16	13	29
International	8	9	17
Kenworth	8	4	12
Other	9	9	18
Vehicle configuration:			
Tractor semitrailer	53	30	83
Tractor/two twin trailers	8	8	16
Straight truck	1	7	8
Tractor type:			
Conventional	40	18	58
Cab over engine	22	26	48
Data not available	0	1	1
Trailer type:			
Van trailer	31	15	46
Flatbed trailer	7	14	21
Tanker	7	8	15
Refrigerated trailer	10	0	10
Other	7	8	15
Model year:			
1990–1993	21	13	34
1985–1989	26	14	40
1980–1984	10	12	22
1970–1979	5	6	11
Vehicle weight (pounds gross vehicle weight):			
70,000–80,000	32	24	56
50,000–69,999	15	6	21
30,000–49,999	11	5	16
22,000–29,999	3	8	11
Data not available	1	2	3

Appendix C

Distributions of Duty and Sleep Measures

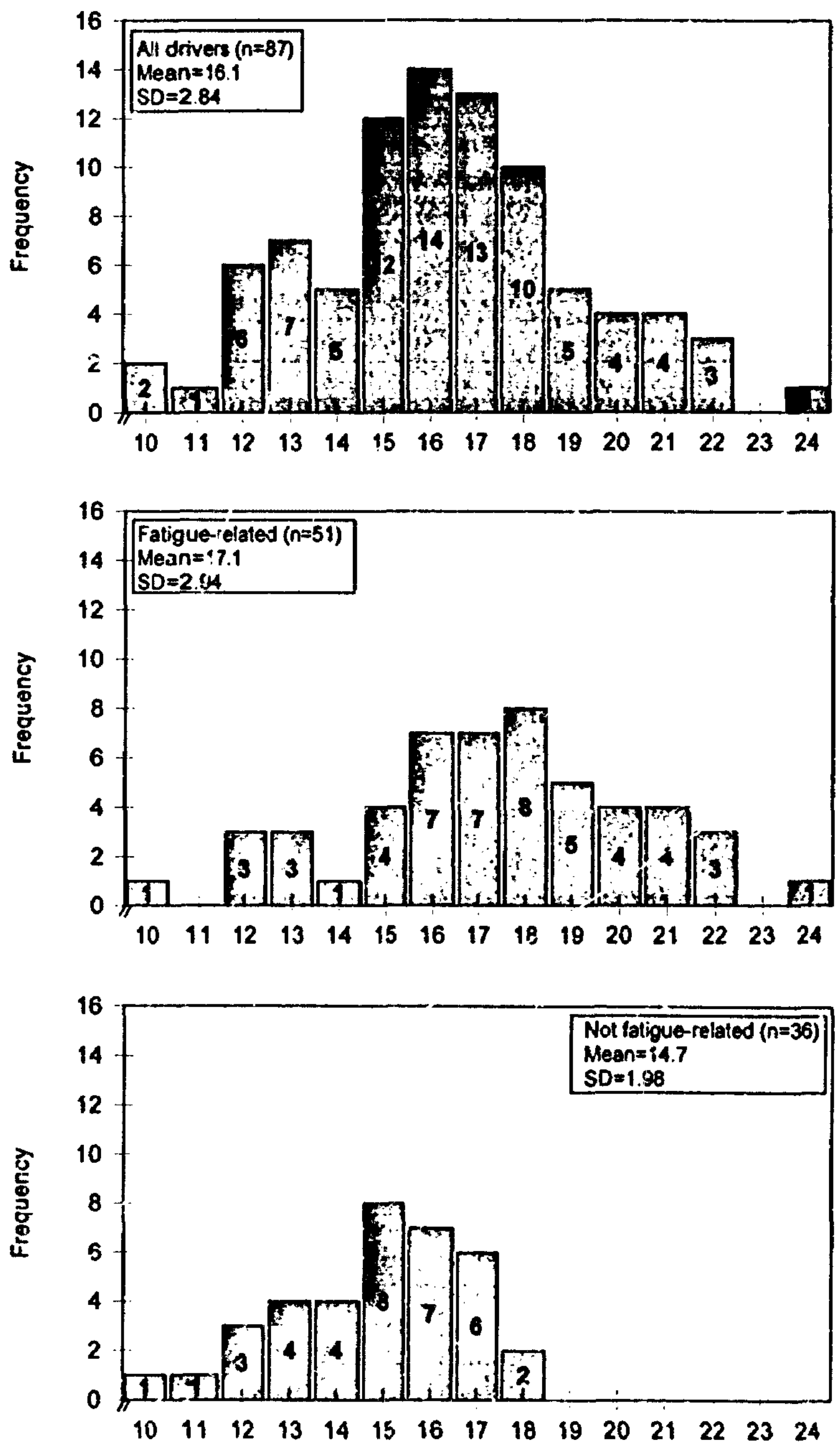


Figure C.1—Distribution of number of hours awake in past 24 hours.

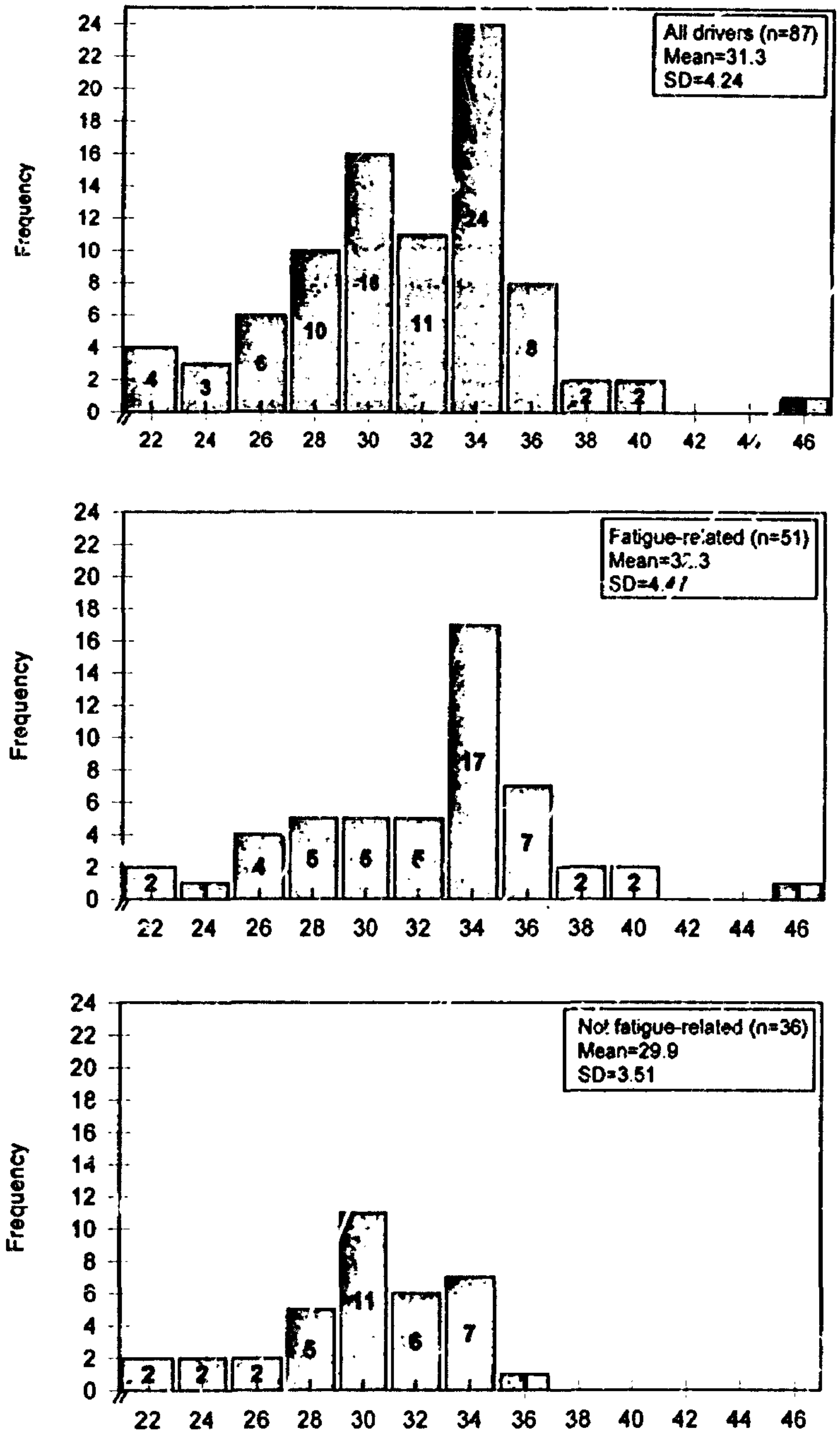


Figure C.2—Distribution of number of hours awake in past 48 hours.

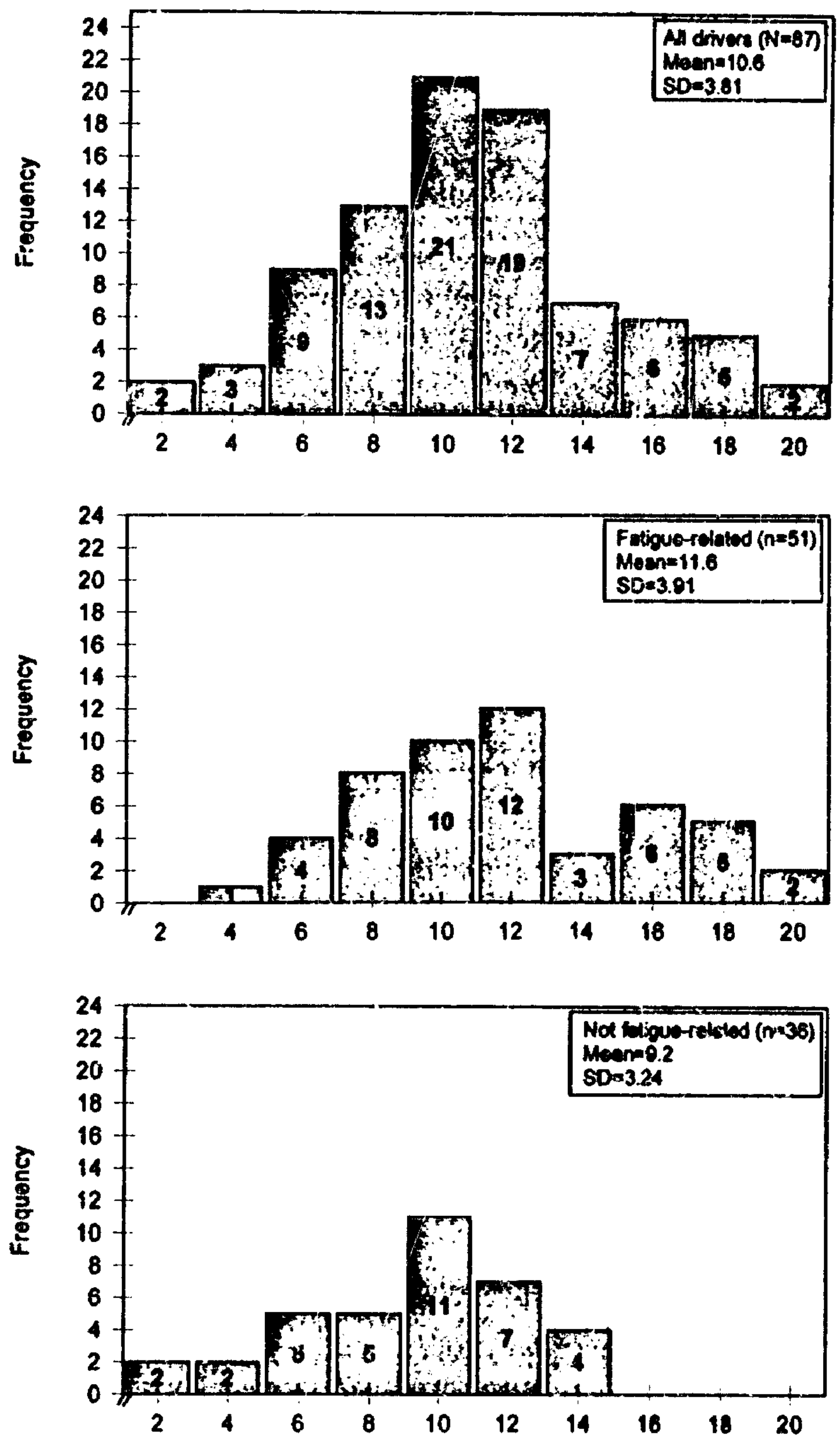


Figure C.3—Distribution of number of hours on duty in past 24 hours.

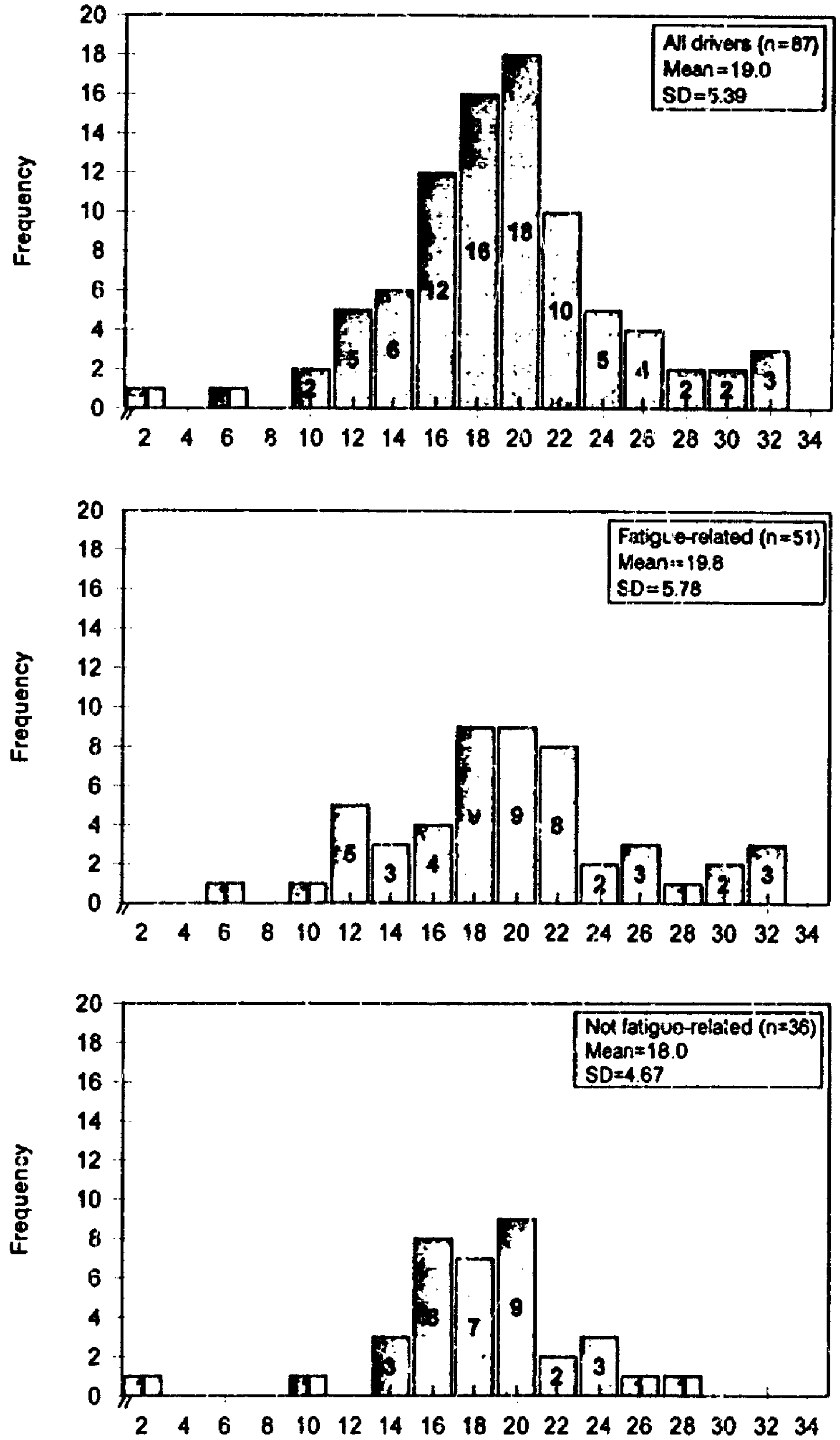


Figure C.4—Distribution of number of hours on duty in past 48 hours.

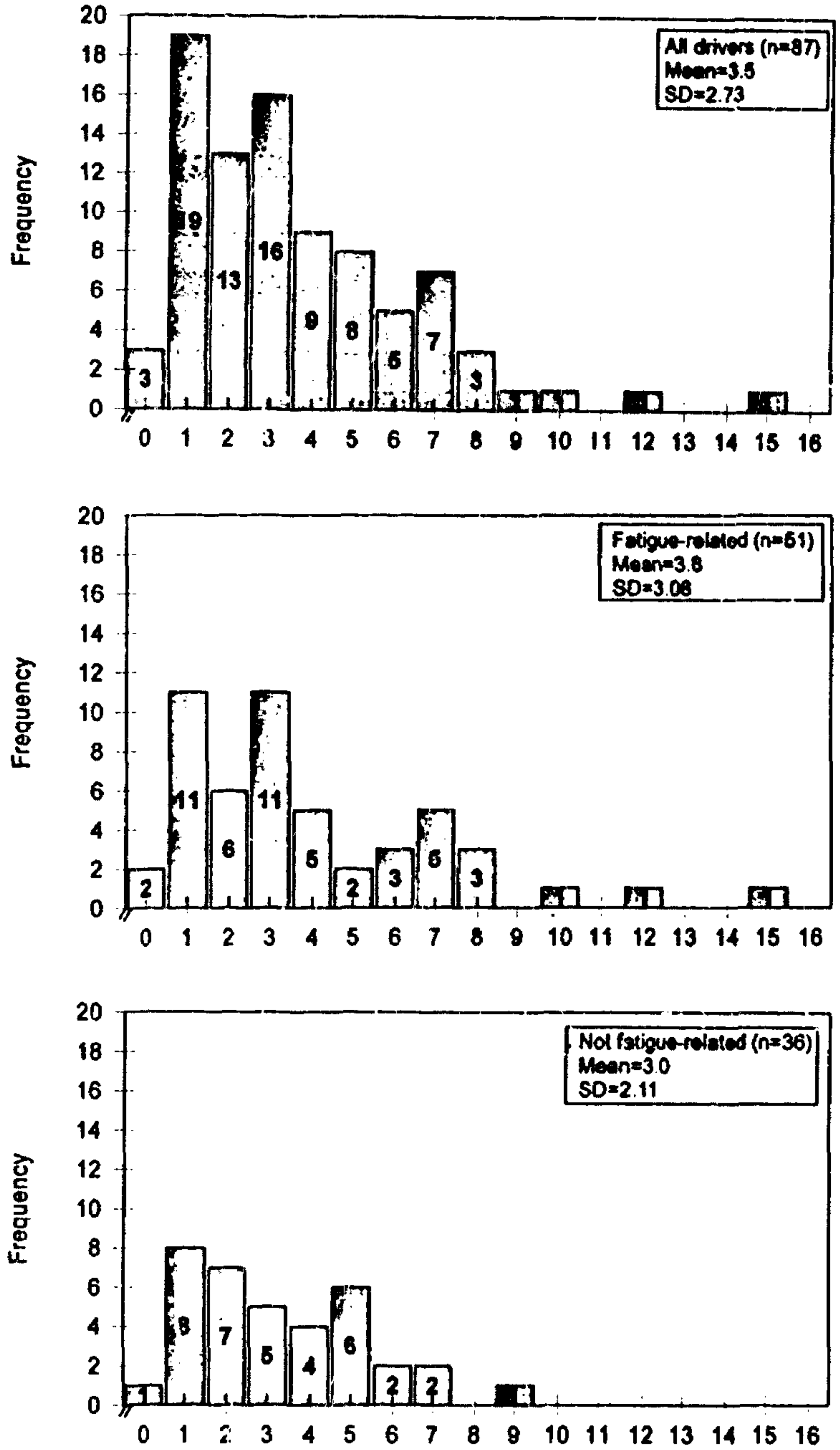


Figure C.5—Distribution of number of hours on duty in most recent duty period.

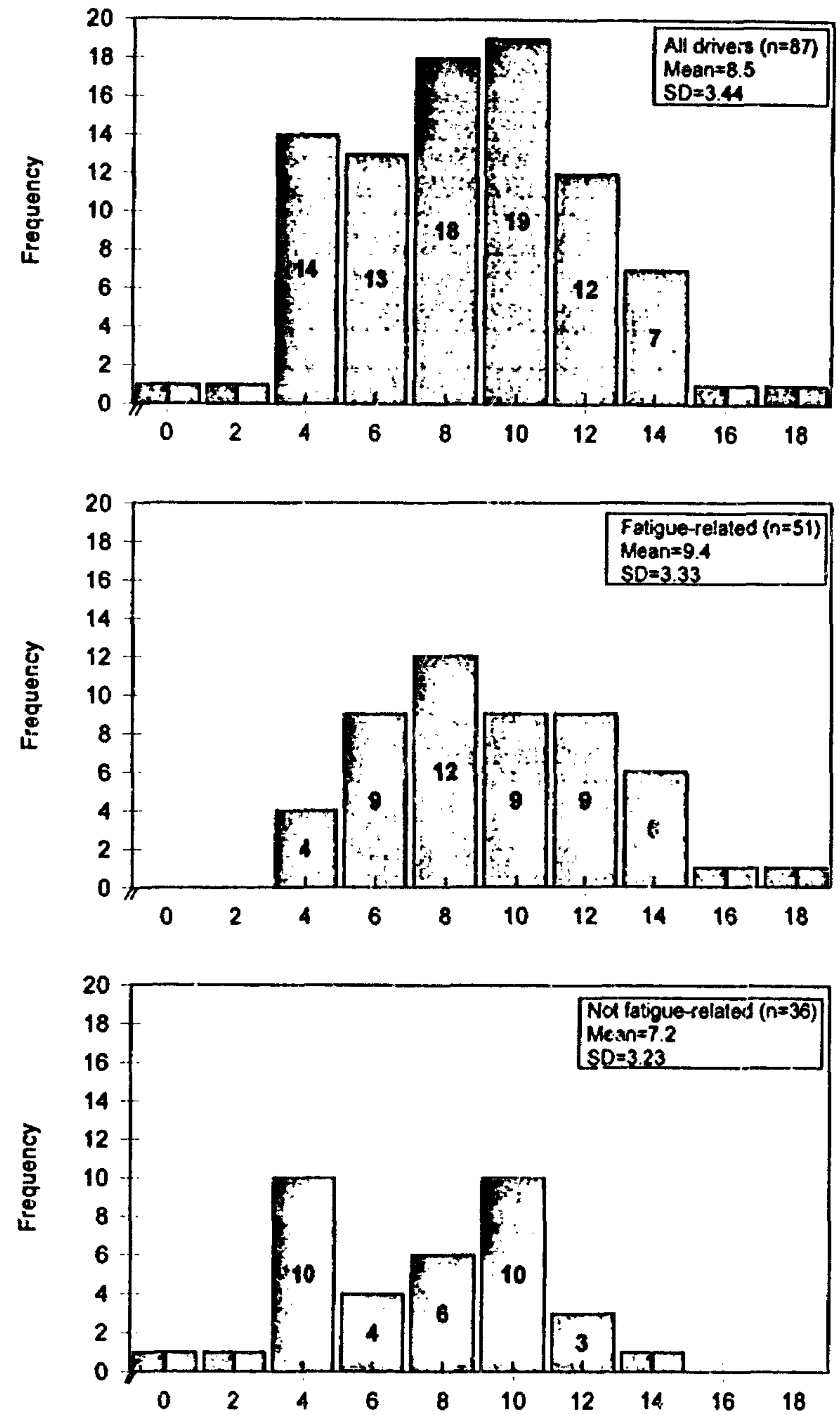


Figure C.6—Distribution of number of hours driving in past 24 hours.

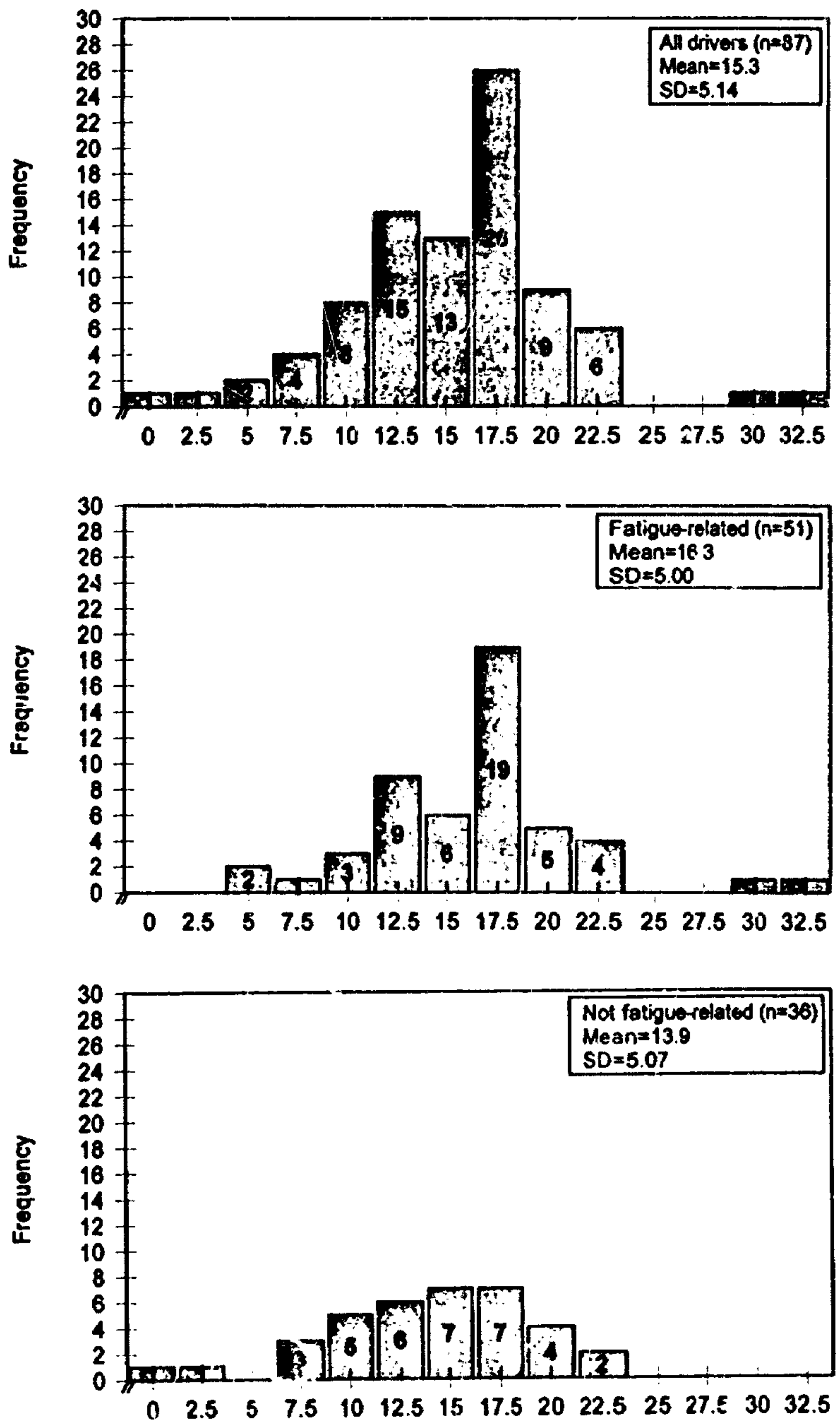


Figure C.7—Distribution of number of hours driving in past 48 hours.

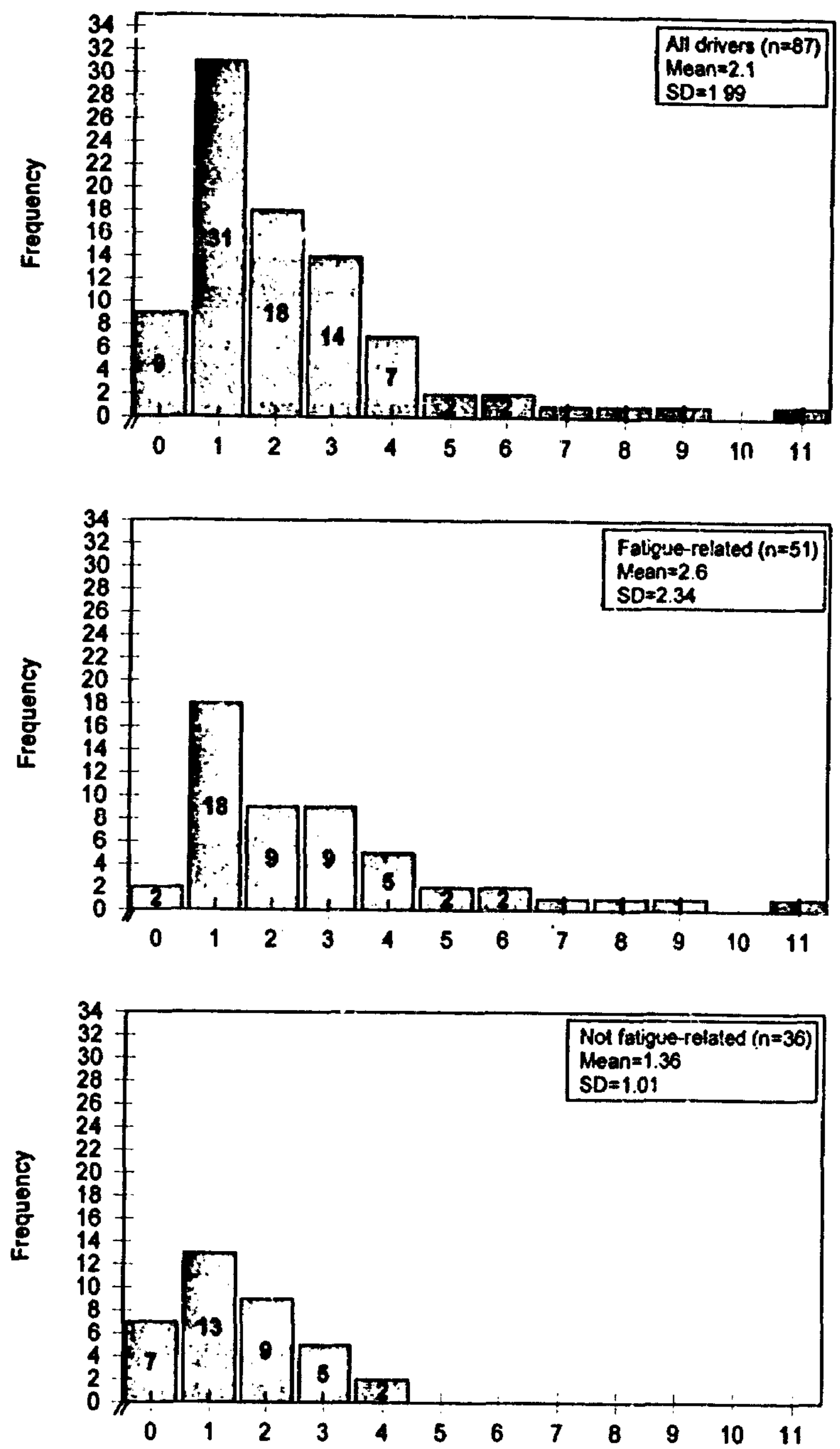


Figure C.8—Distribution of number of hours driving in most recent driving period.

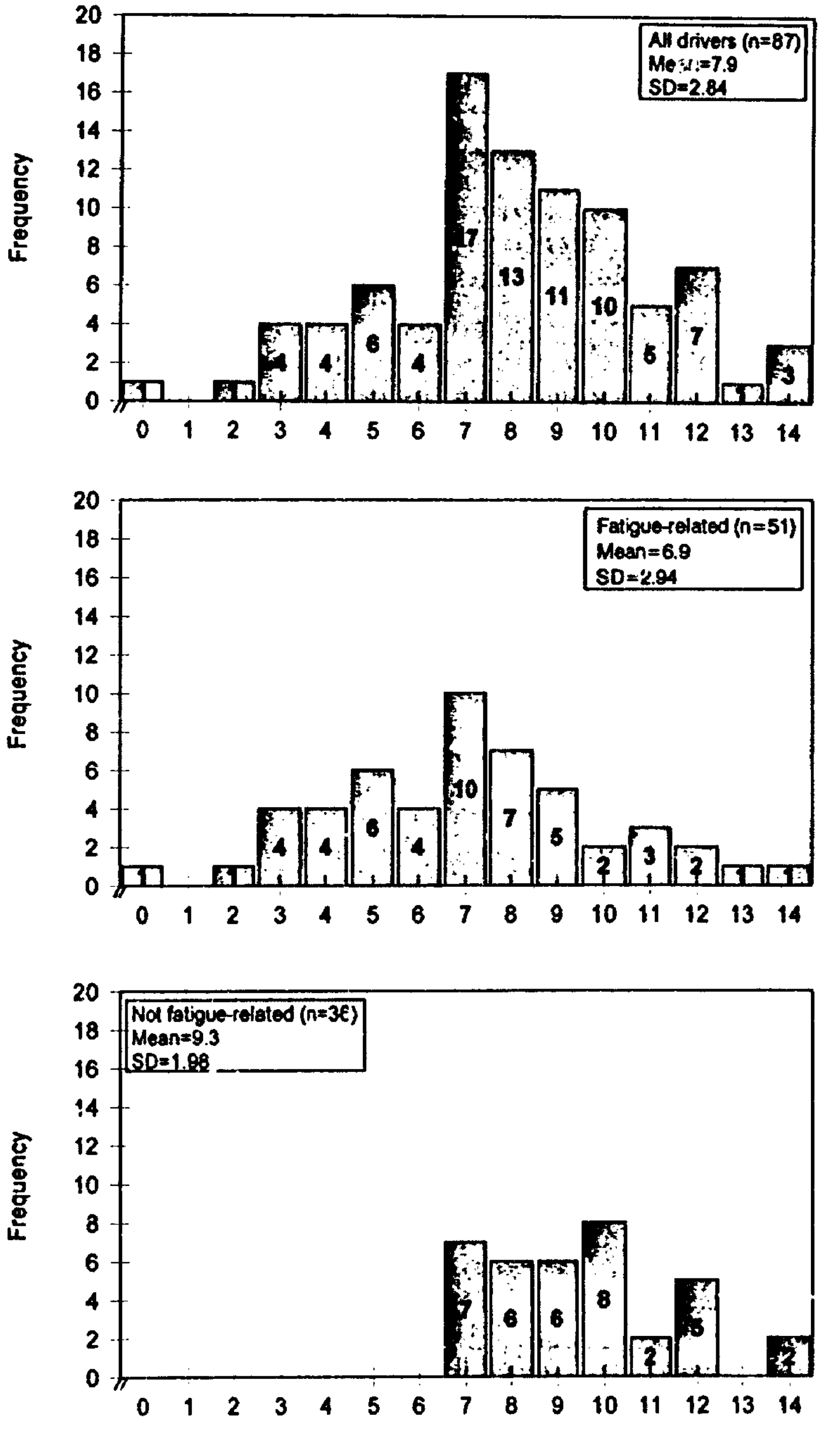


Figure C.9—Distribution of number of hours slept in past 24 hours.

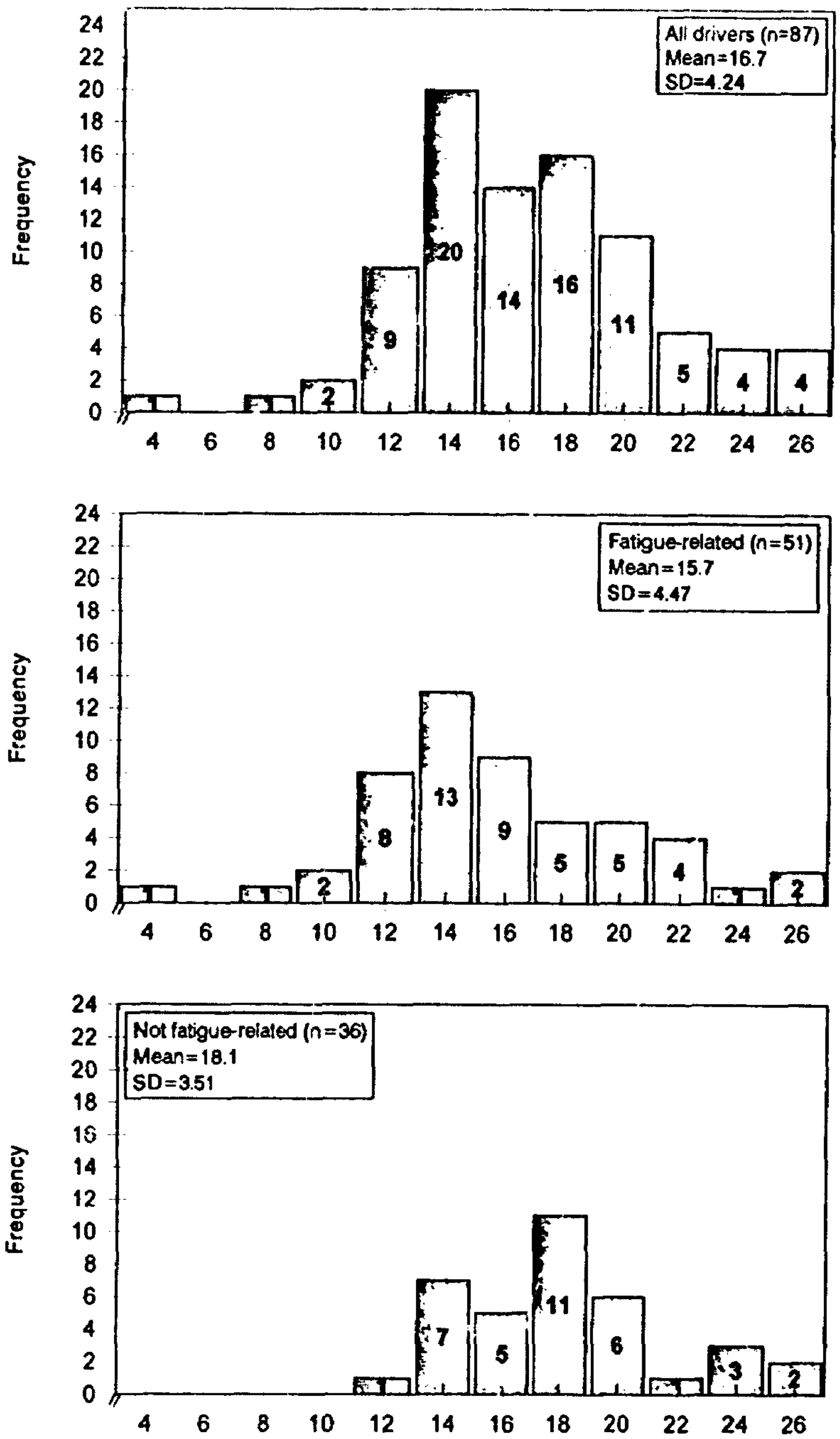


Figure C. -Distribution of number of hours slept in past 48 hours.

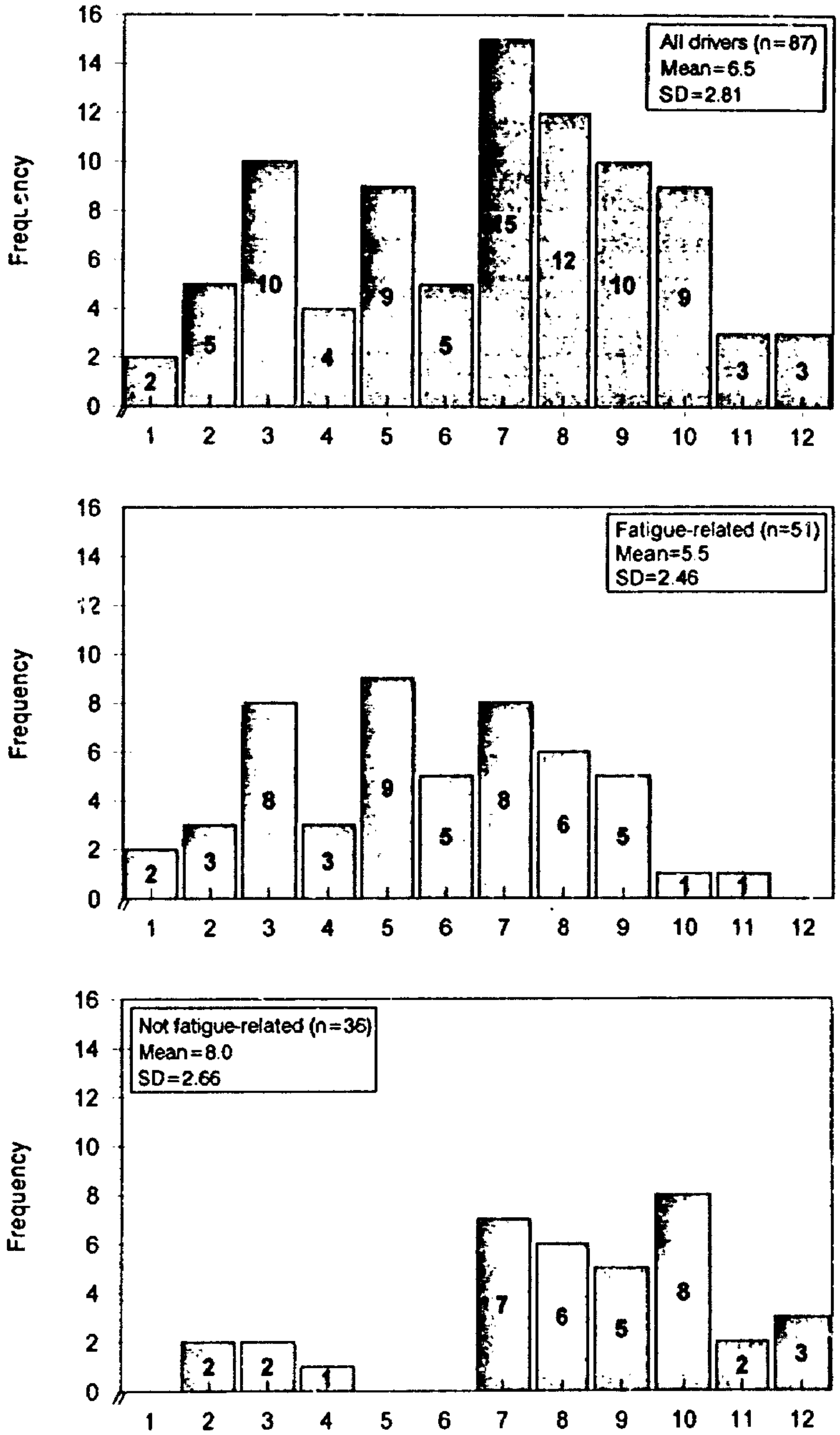


Figure C.11—Distribution of number of hours slept in most recent sleep period.

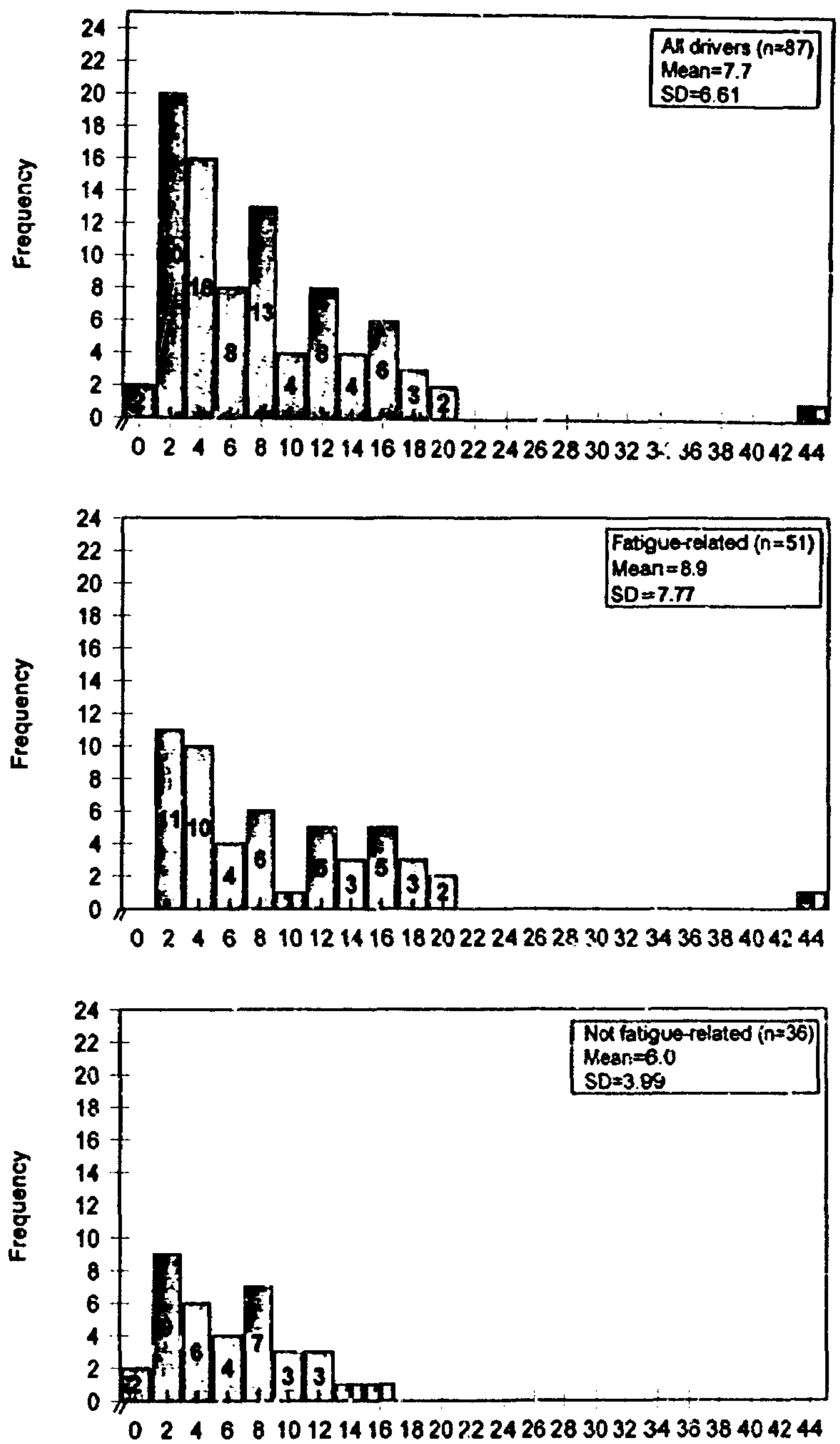


Figure C.12—Distribution of number of hours since last slept.

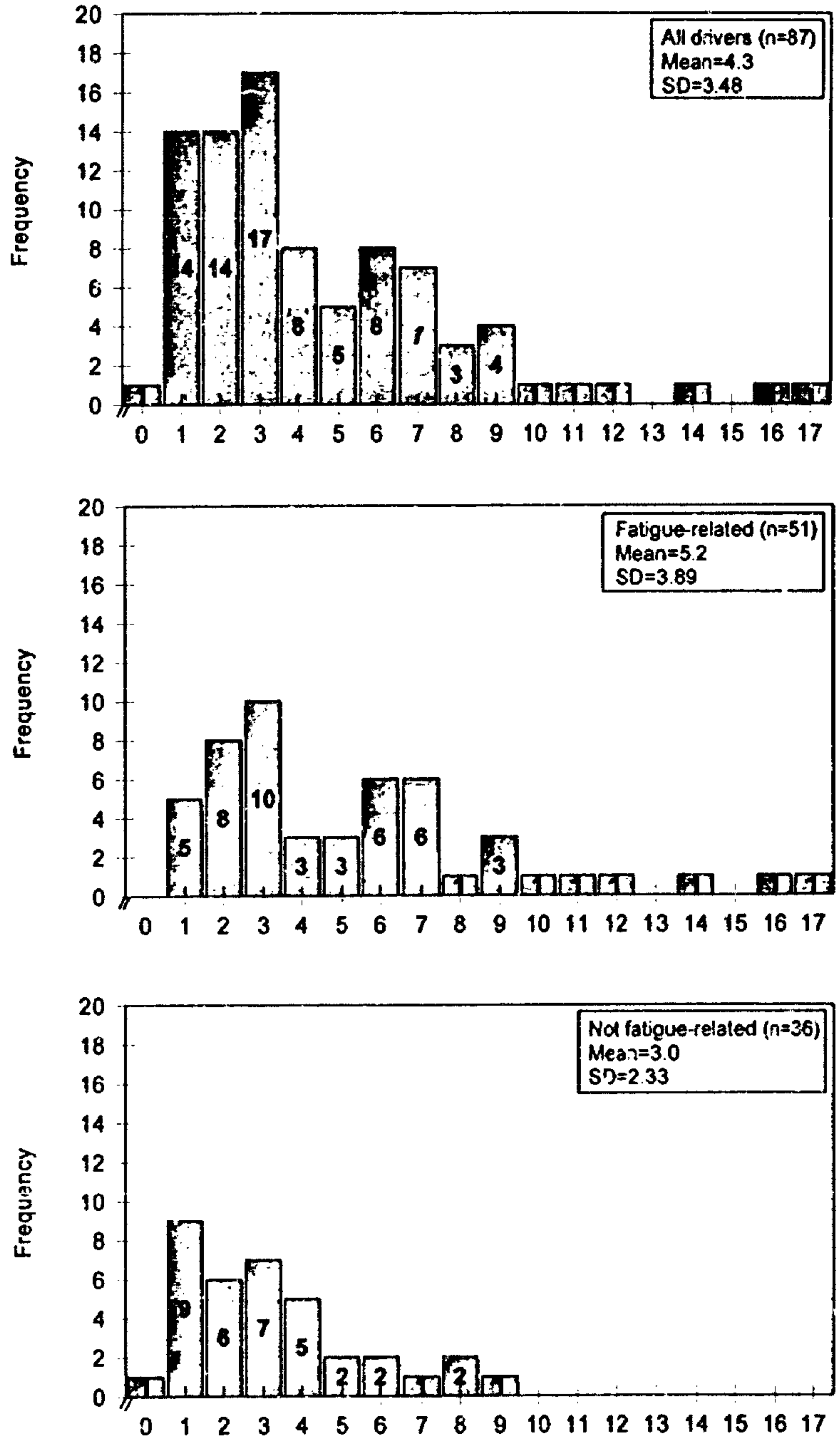


Figure C.13—Distribution of number of hours driving since last slept.

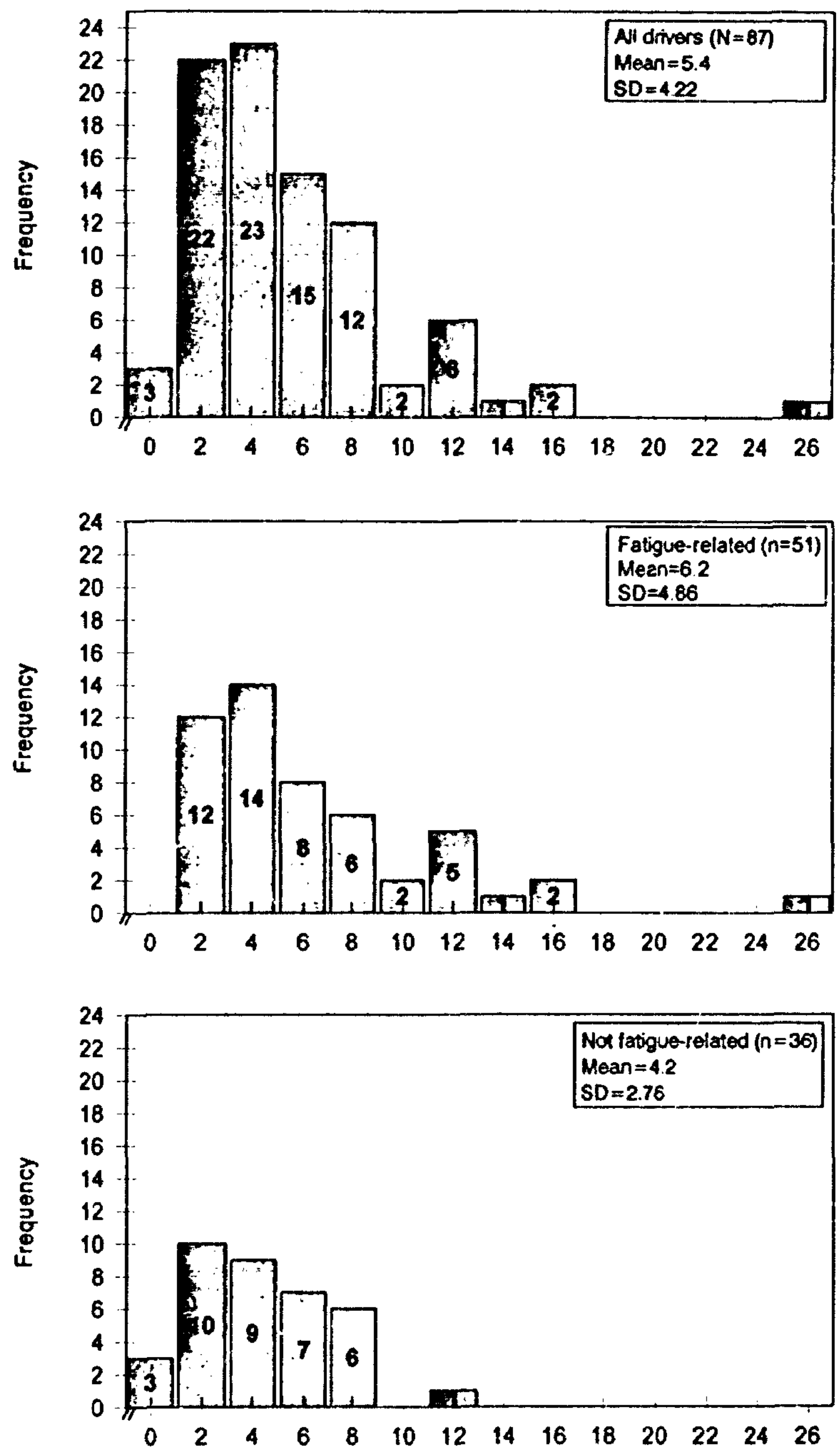


Figure C.14—Distribution of number of hours on duty since last slept.

Appendix D

Details of Discriminant Function Analysis

Fatigue-Related Versus Nonfatigue-Related Accidents

Discriminant analysis determines the weighted combination of sleep, duty, and scheduling measures that produces the maximum separation between the groups. The statistical significance of the discriminant analysis is assessed by the chi square (χ^2) approximation to the Wilks' Lambda statistic (Λ),[1] which is a measure of between groups to within groups variation. The discriminant analysis also assesses the correlation between each of the sleep, duty, and scheduling measures and the discriminant score. The sleep, duty, and scheduling variables are entered into the discriminant analysis simultaneously.

The 87 cases with complete data were used for the analysis. One rule of thumb regarding minimum sample sizes for discriminant analysis is that the size of the smallest group should exceed the number of predictor variables.[2] The present analysis exceeds this recommendation as there are 18 predictor variables and 36 cases falling into the smallest group, which is the drivers in nonfatigue-related accidents.

Figure D.1 shows the distributions of discriminant scores for the drivers in fatigue- and nonfatigue-related accidents. The discriminant analysis was statistically significant (Λ=0.541; χ^2=46.66, df=18, p=0.0002). Superimposed on this figure are the means of the discriminant scores for the two groups. As can be seen in the figure, the distributions of discriminant scores are clearly distinct for the two groups. The discriminant scores for the drivers in fatigue-related accidents tend to be clustered toward the positive end (mean=0.76) of the scale whereas the discriminant scores for the drivers in nonfatigue-related accidents (mean=−1.08) are skewed toward the lower, negative end of the scale.

---

[1] The significance of the discriminant analysis is assessed by determining the extent to which the between groups variance, or the separation between the discriminant score distributions of the two groups, is large, relative to the variability of discriminant scores within each group. A primary index of this separation between the groups is provided by the Wilks' Lambda statistic, the statistical significance of which is approximated by the chi square.

[2] Tabachnick and Fidell (1989).

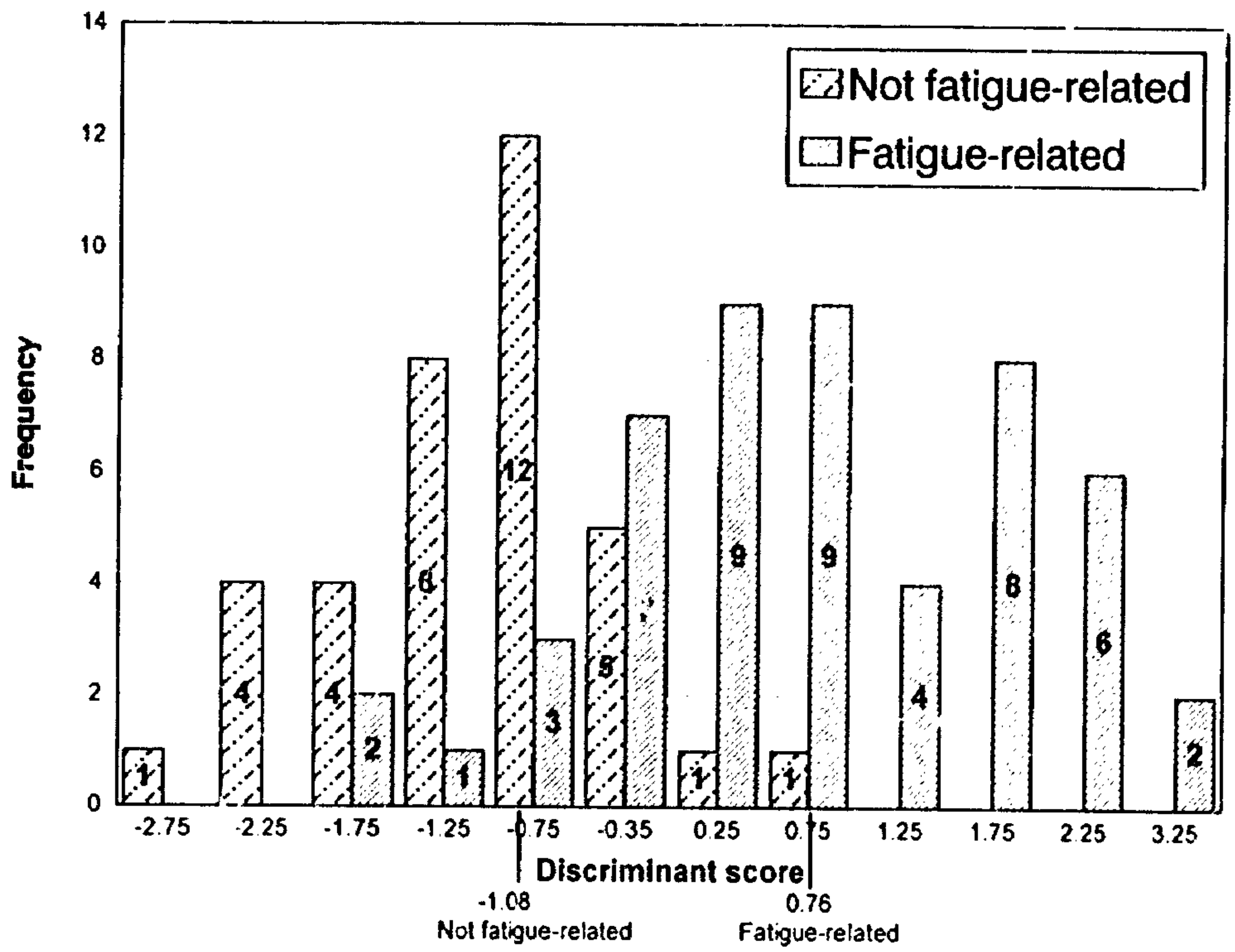


Figure D.1—Frequency distributions of discriminant scores for drivers in fatigue-related and nonfatigue-related accidents.

The three most important measures in classifying accidents as fatigue-related or nonfatigue-related were the duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep. The correlation matrix in table D.1 shows only moderate correlations between duration of sleep in the last period and the number of hours of sleep in the last 24 hours (r=0.35), and between duration of last sleep period and split sleep (r=0.56), and essentially no correlation between split sleep and amount of sleep in the last 24 hours (r=0.02). A set of measures representing recent duration of driving and on-duty time, as well as exceeded hours-of-service limits were the next most influential variables in the discriminant analysis.

An advantage of using discriminant analysis is that it provides both a means of determining whether the set of measures can correctly classify drivers into the two groups as well as an indication of the relative contribution of the measures to the classification. Table D.2 compares the group classification produced by the discriminant analysis with the actual classification based on the investigative procedures. Overall, 86.21 percent of the drivers were correctly classified on the basis

Table D.1—Correlation matrix for discriminant analysis

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Duration of most recent sleep period (hours)	--																	
2. Number of hours slept in past 24 hours	.35	--																
3. Number of hours slept in past 48 hours	.21	.83	--															
4. Duration of most recent driving period (hours)	-.10	-.10	.01	--														
5. Number of hours driving in past 24 hours	-.36	-.27	-.09	.41	--													
6. Number of hours driving in past 48 hours	-.18	.01	.05	.38	.73	--												
7. Duration of most recent duty period (hours)	.01	-.13	-.14	.59	.15	.14	--											
8. Number of hours on duty in past 24 hours	-.41	-.47	-.32	.25	.83	.56	.23	--										
9. Number of hours on duty in past 48 hours	-.21	-.18	-.18	.24	.56	.78	.30	.73	--									
10. Number of hours since last slept	.13	-.42	-.49	.18	.02	.17	.25	.13	.22	--								
11. Number of hours driving since last slept	-.04	-.38	-.38	.51	.45	48	.45	.42	.42	.80	--							
12. Number of hours on duty since last slept	-.01	-.40	-.45	.33	.28	.33	.47	.40	.41	.88	.94	--						
13. Fragmented sleep pattern (yes/no)	-.56	.02	.08	-.04	.27	.25	-.24	.22	.16	-.07	-.01	-.03	--					
14. Inverted duty/sleep pattern (yes/no)	.04	-.27	-.15	.21	.07	.05	.15	.06	.03	.30	.23	.16	-.16	--				
15. Exceeded hour-of-service limits (yes/no)	-.41	-.37	-.25	.30	.54	.41	.17	.56	.43	.11	.34	.29	.24	.01	--			
16. Irregular duty pattern (yes/no)	-.24	.02	.11	.21	.24	.28	-.22	.00	-.08	.18	.25	.11	.36	.24	.26	--		
17. Irregular sleep pattern (yes/no)	-.30	.14	.21	.30	.34	.38	-.04	.16	.16	.00	.20	.09	.47	-.01	.31	.55	--	
18. Irregular duty/sleep pattern (yes/no)	-.29	.12	.20	.31	.32	.36	-.07	.11	.09	.03	.22	.10	.48	.01	.25	.65	.93	--

Table D.2—Number of fatigue-related and nonfatigue-related accidents, as classified by the probable cause of each accident; and predicted accident group classification, based on the discriminant function scores for each driver[a]

Accident group, classified by probable cause[b]	Number of accidents in group	Predicted accident group classification[c] and portion of the accident group classified by probable cause: Fatigued-related	Predicted accident group classification[c] and portion of the accident group classified by probable cause: Nonfatigued-related
		- - - Number of accidents - - -	
Fatigue-related	51	41 (80.4%)	10 (19.6%)
Nonfatigue-related	36	2 (5.6%)	34 (94.4%)

[a] There were 107 cases in the accident sample; however, the discriminant function analysis was performed on 87 cases for which data on all the variables were available.

[b] The probable cause of each accident was determined by results of the accident investigation.

[c] Based on the discriminant function scores of each driver.

of the discriminant analysis. Drivers in nonfatigue-related accidents were correctly classified 94.4 percent of the time and drivers in fatigue-related accidents were correctly classified 80.4 percent of the time.

Figure D.2 is a scatter plot showing the relationship between the discriminant scores and the duration (in hours) of the last sleep period. The slope of the regression line in this figure reflects the negative correlation between the discriminant scores and the duration of last sleep. The plot shows that the drivers in fatigue-related accidents tended to have short periods of sleep in their last sleep period, whereas the drivers in nonfatigue-related accidents generally had much longer periods of sleep, and low, negative discriminant scores. Outliers (drivers in fatigue-related accidents with substantial sleep in their last sleep period, or drivers in nonfatigue-related accidents with only a little sleep in the last sleep period) were also examined. The drivers in cases 15, 23, and 28 were found to have had 11, 8.5, and 8.5 hours of sleep, respectively, in their last sleep period, but had only a small amount of sleep in the

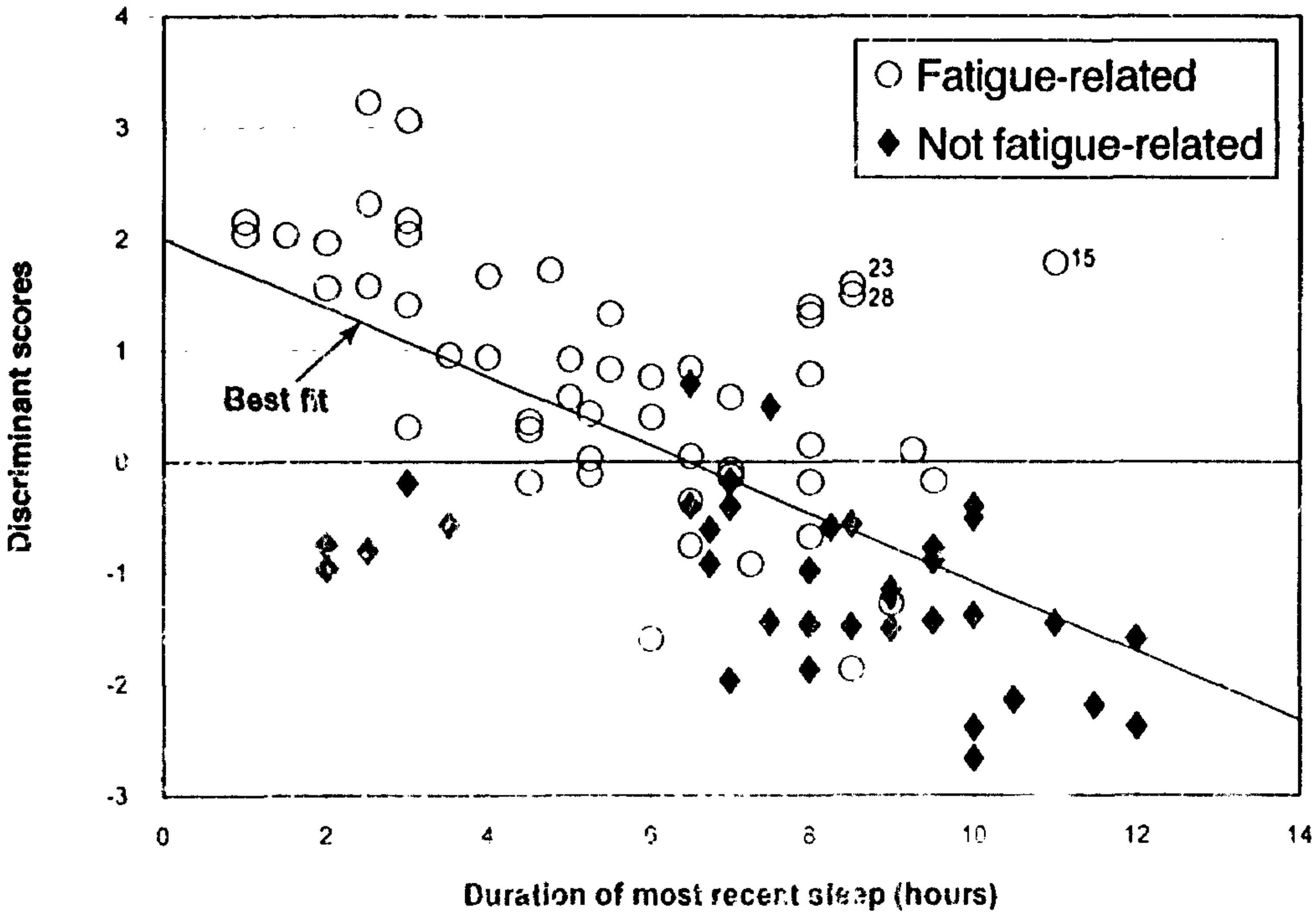


Figure D.2—Scatter plot of discriminant scores for drivers in fatigue-related and nonfatigue-related accidents by duration of most recent sleep period (hours).

past 24 hours (3.75 hours, 3.5 hours, and 6.5 hours, respectively) as well as exhibiting inverted sleep schedules.[3]

Figure D.3 provides a similar plot of the relationship between the discriminant scores and the amount of sleep in the past 24 hours. There is again a negative relationship between the discriminant scores and the number of hours slept in the last 24 hours, as shown by the regression line in the figure. There were some drivers who had relatively large amounts of sleep in the past 24 hours but were involved in fatigue-related accidents. Some of these drivers (cases 13, 22, 76, 94, and 106) had split sleep. Although each of these drivers had more than 10.5 hours of sleep in the past 24 hours, the amount of sleep in their last sleep period was only 5.25, 3.0, 5.25, 4.25, and 4.0 hours, respectively. For example, in case 13, the driver had 11.75 hours of sleep in the past 24 hours; however, that sleep was obtained in three sleep periods of 4, 4.5, and 5.25 hours.

---

[3] These drivers had been awake long hours as a result of their inverted schedules: 20.25, 20.5, and 17.5 hours, respectively.

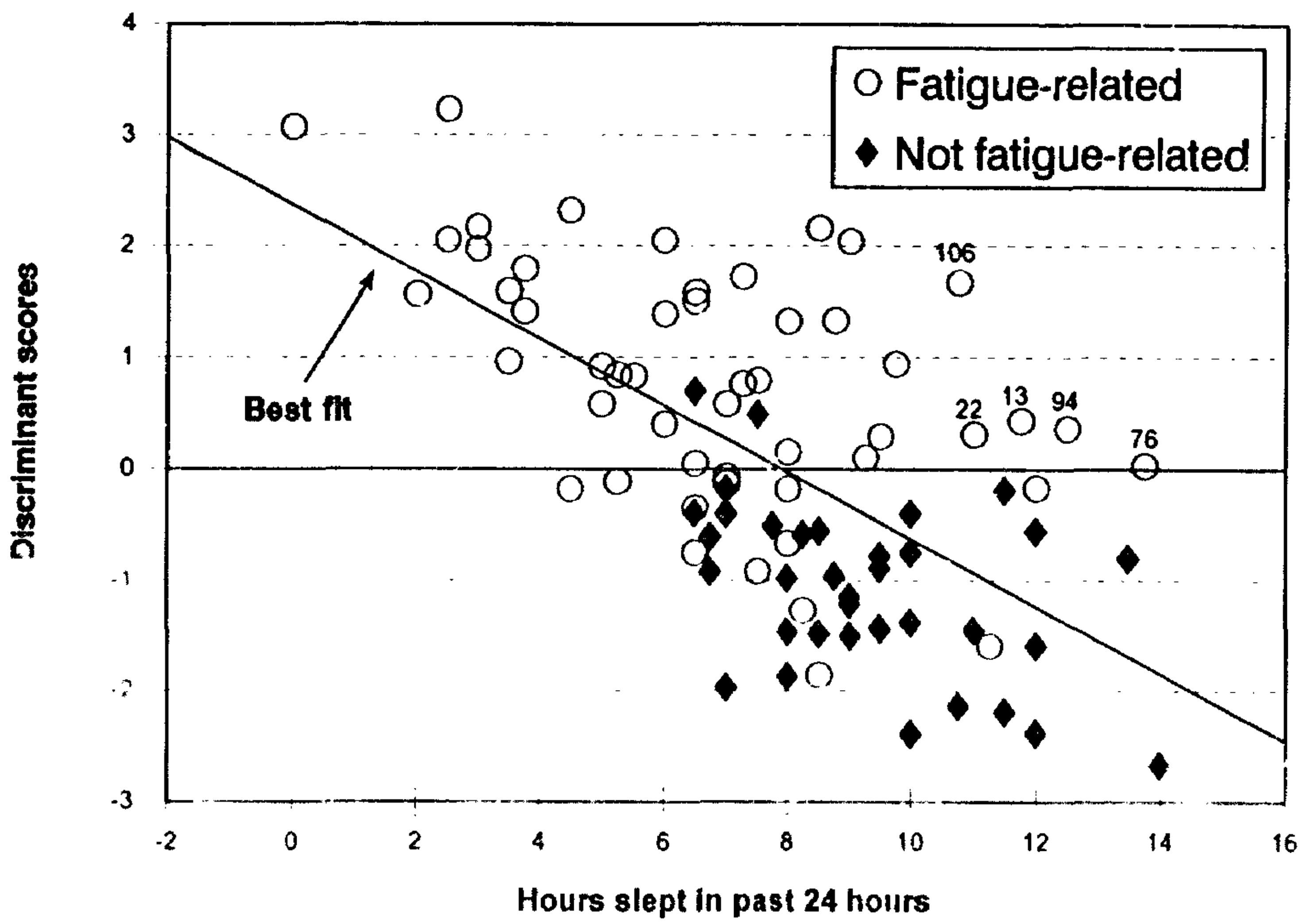


Figure D.3 Scatter plot of discriminant scores for drivers in fatigue-related and nonfatigue-related accidents by number of hours slept in the past 24 hours.

Long-Haul Versus Short-Haul Operations

The discriminant function analysis of the 18 measures was able to discriminate clearly between the long- and the short-haul groups (Λ=0.54; χ^2=47.14, df=18, p=0.0002). (See figure D.4.) Table D.3 compares group membership (long or short haul) based on the discriminant function score with group membership based on actual driving assignment. Overall, 79.31 percent of the drivers were correctly classified by the discriminant function analysis. The discriminant function analysis was better able to classify correctly the long-haul drivers (87 percent correctly classified) than the short-haul drivers (70.7 percent correctly classified).

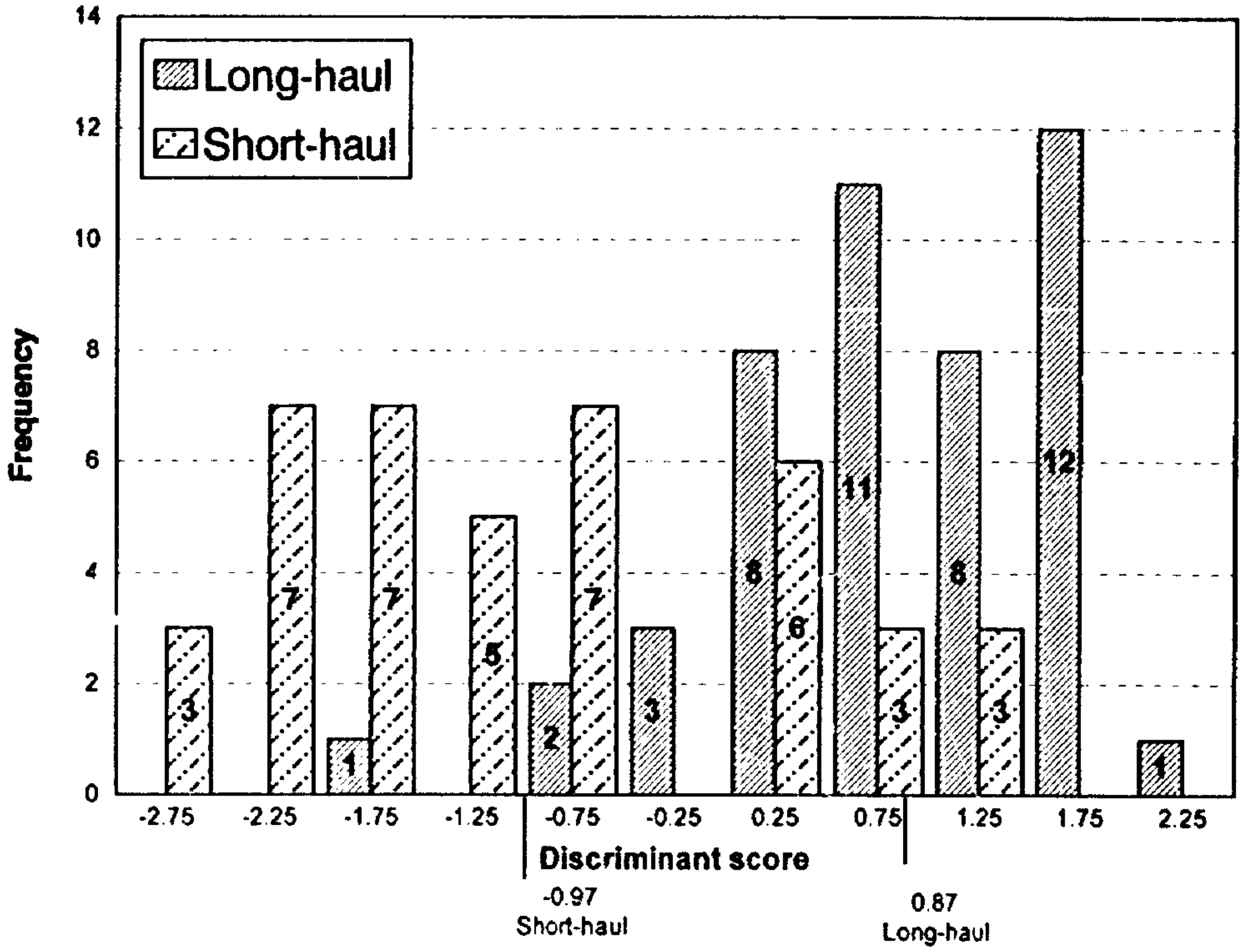


Figure D.4—Frequency distributions of discriminant scores for drivers on long-haul and short-haul operations.

Table D.3—Number of drivers in the accident sample with long-haul and short-haul driving assignments, based on information from the accident investigation; and predicted driving assignment, based on the discriminant function scores for each driver[a]

Driving assignment, based on accident investigation	Number of drivers with the assignment	Predicted driving assignment[b] and portion of the assignment as based on the investigation	
		Long-haul	Short-haul
		Number of accidents	
Long haul	46	40 (87.0%)	6 (13.0%)
Short haul	41	12 (29.3%)	29 (70.7%)

[a] There were 107 cases in the accident sample; however, the discriminant function analysis was performed on 87 cases for which data on all the variables were available.

[b] Based on the discriminant function scores of each driver.

END
FILMED

DATE:
3-16-95

NTIS